AD-A151 418 DIGITAL TROPOSCATTER PERFORMANCE MODEL USERS MANUAL(U) 1/4
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A-288-15 DCA100-80-C-0030

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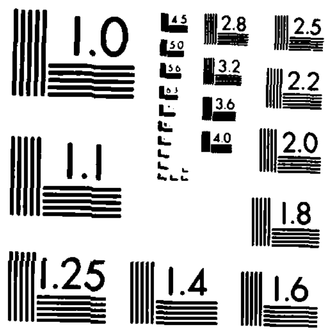

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DIGITAL TROPOSCATTER PERFORMANCE MODEL:
USERS MANUAL

Contract No. DCA100-80-C-0030
SIGNATRON Reference A288-15

November 1983

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REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER	2. GOVT ACCESSION NO.
3. RECIPIENT'S CATALOG NUMBER	
4. TITLE (and Subtitle) Digital Troposcatter Performance Model: Users Manual	5. TYPE OF REPORT & PERIOD COVERED Final June 1980-November 1983
	6. PERFORMING ORG. REPORT NUMBER A288-15
7. AUTHOR(s) P. Monsen, S. Parl, A. Malaga, S. Tolman J. Fetteroll	8. CONTRACT OR GRANT NUMBER(s) DCA100-80-C-0030
9. PERFORMING ORGANIZATION NAME AND ADDRESS SIGNATRON, Inc. 12 Hartwell Avenue Lexington, MA 02173	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS Defense Communications Agency Washington, D.C. 20305 ATTN: Code 680	12. REPORT DATE November 1983
	13. NUMBER OF PAGES 348
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office) Defense Communications Agency Defense Communications Engineering Center 1860 Wiehle Ave., Reston, VA 22090 ATTN: R220	15. SECURITY CLASS. (of this report) UNCLASSIFIED
	15a. DECLASSIFICATION/DOWNGRADING SCHEDULE N/A

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Troposcatter	Propagation Prediction
Diffraction	Multipath Prediction
MD-918 Modem	Error Rate Prediction
AN/TRC-170	Link Analysis

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A complete software program for the analysis and evaluation of digital troposcatter communication links is described. The computer program TROPO is intended to provide an accurate prediction model of the troposcatter and/or diffraction propagation path at frequencies between 100 MHz and 35 GHz for all types of diversity receiver configurations used in the DCS, and the prediction of the performance of the MD-918 and AN/TRC-170 troposcatter modems. The program can also evaluate the performance of other modems if a performance prediction model is provided by the user. TROPO (over)

20. Abstract (continued)

takes into account a number of practical factors such as the effects of RF interference, RF bandwidth constraints, actual diversity antenna geometry, climate and atmospheric characteristics. This document is the User's Manual.

FOREWORD

This document is of the Users Manual for the computer program TROPO developed under Defense Communications Agency Contract DCA100-80-C-0030. The computer program TROPO is intended to provide an accurate prediction model of the troposcatter and/or diffraction propagation path for all types of diversity receiver configurations used in the Defense Communications System (DCS), and prediction of the performance of both the MD-918 and AN/TRC-170 digital troposcatter modems. The program can also evaluate the performance of other modems if a performance model is provided by the user. TROPO takes into account a number of practical factors such as the effects of RF interference, RF bandwidth constraints, actual diversity antenna geometry, climate and atmospheric characteristics.

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INTRODUCTION

TROPO is a flexible program for the prediction of single link digital troposcatter communications system performance. It can be used to calculate the troposcatter path loss distribution and power per unit delay (multipath) profile of a specific troposcatter link and the correlation between diversity ports for standard diversity configurations. It can calculate the propagation loss and other propagation parameters for mixed-mode diffraction and troposcatter paths. TROPO can also be used to calculate the short-term performance (over a 1-hour period) and long term performance (over a year) of the MD-918 and AN/TRC-170 modems or a user-modeled modem. For the MD-918, and the AN/TRC-170, it can calculate short-term bit error rates, 1000 bit block error rates, short-term and yearly average outage probability, taking into account the effects of realistic RF band-limiting (i.e., filtering) and co-channel and adjacent channel interference.

The program includes a number of convenience features:

(1) Path Loss Variability data for the climate zones specified in National Bureau of Standards (NBS) Tech Note 101 as well as for those given in MIL-HDBK-417 are provided internally to the program. Provision is also made for the user to specify his own climate variability data.

(2) The program will optionally compute horizon elevation angles and effective antenna heights above average terrain height if the user does not wish to supply this data directly.

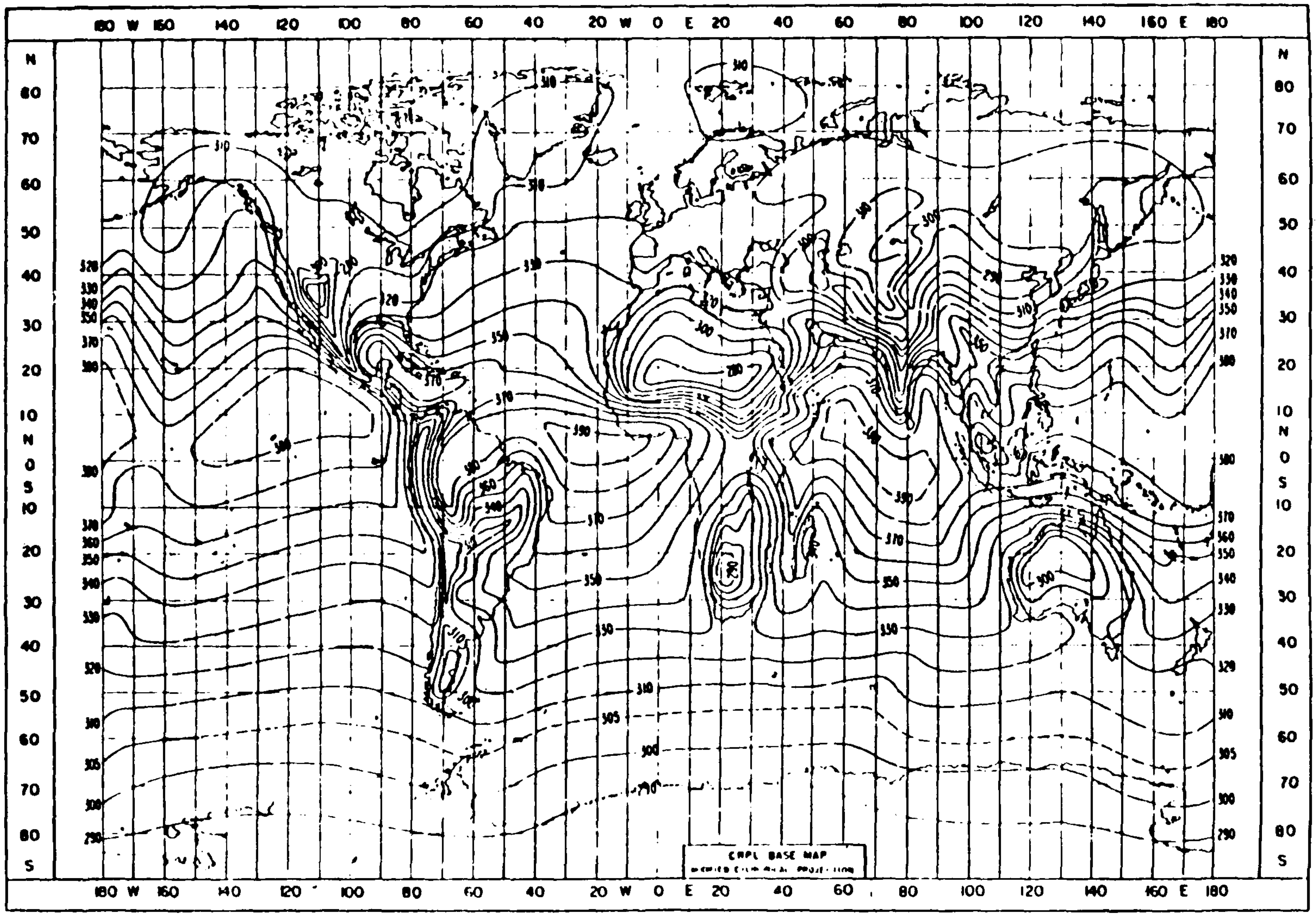

Figure 2-3 (From Rice, et al., 1967)

where h_s is the elevation of the surface above sea level in km. In beyond-the-horizon paths, h_s is determined at the two radio horizons along the great circle path between the antennas, and N_s is taken as the average of two values calculated from the above relationship. The minimum monthly mean value of N_0 (referred to hereafter as SEAN) has been chosen by NBS Tech Note 101 and the MIL-HDBK-417 for the calculation of the refractive bending effects on the reference path loss L_r because they are representative of winter conditions (i.e., weak signal periods).

If the user specifies both SEAN and ERFAC, the program ignores the value supplied for ERFAC and calculates a new effective earth radius factor according to the above relationships. The reason for choosing SEAN as the independent parameter is because the median correction factor, $V(d_e)$ (coded VDE), and variability about the median $Y_0(q)$, defined in NBS Tech Note 101 and the MIL-HDBK-417 are predicated on the use of the minimum monthly mean sea level refractivity SEAN for the calculation of the reference path loss L_r. Typical values for SEAN are shown in Figure 2-3. They range from 290 (Antarctica) to 390 (equatorial over sea paths) with values around 300 for continental temperate regions.

Some users may wish to use ERFAC as the independent variable however. If a user chooses the effective earth radius factor ERFAC for the calculation of refractive bending effects, then he must enter a value of zero for SEAN. However in this case justification of the use of a median correction factor $V(d_e)$ is required.

A typical value often used for the effective earth radius factor is ERFAC = 4/3. This value is normally regarded as the median for most regions of the world. Since we have established that there is a one-to-one correspondence between the refractivity at sea level SEAN, and ERFAC, then an effective earth

where d is the great circle path length and R_e (coded A) is the effective earth radius. This angle along with the antenna patterns determine the path loss.

The refractivity at sea level SEAN and/or the effective *earth radius factor* ERFAC *are* used to take into account the bending of the rays as they propagate through the lower atmosphere in the calculation of THET and THER (and the scattering angle). The user has the option of selecting <u>either</u> SEAN or ERFAC, <u>but not both</u>, for the calculation of ray bending effects because they are <u>not independent</u> parameters. Ray bending is determined for the most part by the gradient of the refractivity within the first kilometer above the surface of the earth. In order to represent rays as straight lines, an effective earth radius R_e is defined in terms of the refractivity gradient, ΔN, as

$$\mathrm{ERFAC} = \frac{R_e}{R} = \frac{1}{1 + R \cdot \Delta N \times 10^{-6}} \qquad (2.5)$$

where R is the true radius of the earth (R = 6373 Km).

The refractivity gradient has, in turn, been found to be empirically related to the surface refractivity, N_S, by [P.L. Rice, et al., 1967]

$$\Delta N/\mathrm{km} = -7.32 \exp(0.005577\ N_S) \quad . \qquad (2.6)$$

The surface refractivity N_S is related to the refractivity at sea level N_0 (coded SEAN) as follows [P.L. Rice, et al., 1967]

$$N_S = N_0 \exp(-.1057\ h_S) \qquad (2.7)$$

2.5.2 The Reference Path Loss

The reference troposcatter path loss is defined as the long-term (yearly) median path loss in continental temperate climate zones during periods of minimum signal strength (winter afternoons).

The calculation of the long-term reference path loss takes into account the effects of path geometry, and ray bending in a standard atmosphere. It requires calculation of the transmitter and receiver horizon elevation angles, THET and THER respectively, from the following user-supplied path geometry data: (a) transmitter and receiver horizon distances, DLT and DLR, (b) transmitter and receiver horizon elevation above sea level, HLT and HLR, (c) transmit and receive site elevation above sea level HTO and HRO, (d) transmit and receive antenna heights above local ground, HT and HR, and (e) either the refractivity at sea level SEAN as in NBS Tech Note 101 [P.L. Rice, et al., 1967] or the effective earth radius factor ERFAC but not both. Effective antenna heights and/or average terrain elevation data are not needed to calculate the horizon elevation angles THET and THER (and hence the reference path loss), but will be needed if the user wishes to calculate the median correction factors $V(d_e)$ and the variability about the median $Y_0(q)$ for a specific climate. The horizon elevation angles THET and THER* are then used to calculate the minimum scattering angle Θ_S (coded THETA0) from

$$\Theta_S = \text{THET} + \text{THER} + d/R_e \qquad (2.4)$$

---

*NOTE: THET and THER are often referred to as antenna take-off angles. However this is not quite correct and can lead to confusion. The antenna take-off angle is the elevation angle at which the antenna (boresight) is pointing and is not necessarily always equal to the horizon elevation.

The median RSL and path loss are related by

$$P(50) = P_t + G_t + G_r - L(50) \tag{2.2a}$$

where P_t is the transmitted power in dBW or dBm, and G_t and G_r are the gains of the transmitting and receiving antennas in dBi. The median path loss (i.e., loss exceeded by half-of-all hourly medians) is defined as

$$L(50) = L_r - V(d_e) \tag{2.2b}$$

where L_r is the long-term (yearly) reference path loss and $V(d_e)$ is a correction factor which depends on the climate zone and the link geometry parameter called the effective path distance (d_e) to be defined later.

Prediction errors are accounted for by defining the RSL not to exceed q% of the year with (service) probability t as

$$P(q,t) = P(q,0.5) - T\sqrt{12.73 + .12\ Y_0^2(q)} \tag{2.3a}$$

where P(q,0.5) is given by Eq. (2.1) and T is related to the service probability t by

$$t = 0.5 + 0.5\ \mathrm{erf}\left(T/\sqrt{2}\right)$$

$$\mathrm{erf}(x) = \frac{2}{\sqrt{\pi}} \int_0^x \exp(-y^2)\ dy \tag{2.3b}$$

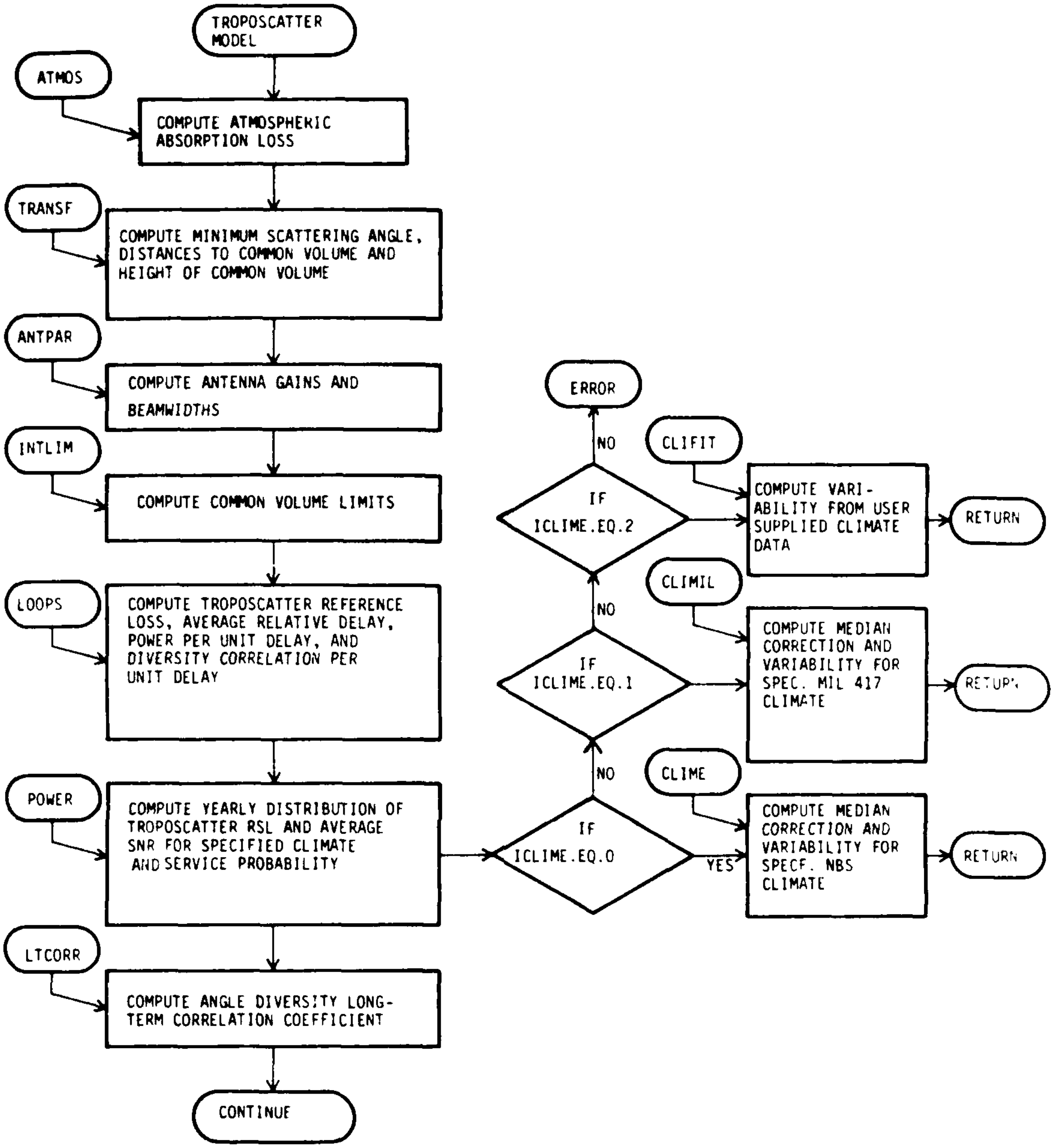

Figure 2-2 Flow Chart for Troposcatter Propagation Parameter Calculations

median and standard deviation of the RSL are accounted for using the service probability* concept described in detail in the Final Report. TROPO also calculates the multipath spread (yearly median) of the channel and if diversity reception is used, it calculates the correlation between the various diversity signals (subroutine LOOPS). A flow chart of the routines involved in the troposcatter propagation calculations is shown in Figure 2-2.

2.5.1 RSL and Path Loss Distributions

The received troposcatter signal is a Rayleigh fading signal which exhibits rapid short-term fluctuations and long-term power fading. The hourly median of the short-term Rayleigh fading is defined as the RSL**. The RSL exceeded q% of the time, P(q), which corresponds to the path loss not exceeded q% of the year, L(q), is defined as

$$P(q) = P(50) + Y_0(q) \quad \text{dBW or dBm}$$

and

$$L(q) = L(50) - Y_0(q) \quad \text{dB} \tag{2.1}$$

where L(50) is the yearly median of the path loss, P(50) is the yearly median of the RSL and $Y_0(q)$ is the variability in the RSL and the path loss about the median.

---

* NOTE: The service probability is the probability that the prediction is correct.

** The average signal level for a Rayleigh fading signal is 1.6 dB above the median.

where feasible. Comment lines in the file (lines beginning with *) serve both to identify to the user what each line of data means and to enable the program to verify that data records are in the proper sequence. Therefore, each block of comment lines must occur in the proper location in the file, must agree verbatim with the required file format (at least in the columns checked by the program), and must contain exactly the number of lines expected by the program.

Depending on the selection of units made for a given TROPO run, the program converts the input units, where necessary, to the standard units used by the program, which are standard MKS units. This conversion is performed by subroutine UNITCV.

2.3 DATA INPUT ERROR DIAGNOSTICS

When something goes wrong with the input file (and experience has shown that this is a major source of difficulty with TROPO), the program sooner or later detects an error. If the error is a data inconsistency, an explanatory error message is printed to the terminal. If the error is an input syntax error the operating system will issue a system error message and terminate.

2.4 PROPAGATION MODES

Two types of propagation conditions can be selected by the user: (1) tropospheric-scatter propagation (PTYPE = 0), or (2) mixed troposcatter-diffraction propagation (PTYPE = 1).

2.5 TROPOSCATTER PROPAGATION MODE

The TROPO program calculates the yearly distribution of the troposcatter path loss and the corresponding RSL (received signal level) for the user specified link geometry and climate zone (subroutine POWER). Errors in the prediction of the yearly

The user can choose to have TROPO perform propagation calculations only or both modem performance and propagation calculations by the appropriate specification of the input parameter MODPAT.

When MODPAT = 0 is selected, the program performs only propagation calculations such as path loss and RSL long term (yearly) distributions, multipath spread and diversity receiver correlations. If MODPAT = 1 is selected, the program performs the propagation calculations and uses them to predict the performance (average bit error rate, 1000 bit block error rate, fade outage* per call minute and fade outage* probability) of the MD-918 modem taking into account the effects of bandwidth constraints and interference as specified by the user. When MODPAT = 2 is selected, the program uses the propagation calculations to predict the performance of the AN/TRC-170 modem (two-frequency) for TRCTYP = 1, or the single frequency DAR modem for TRCTYP = 0. The user can also opt to use propagation calculations to predict the performance of a modem other than the MD-918 or TRC-170 modems by specifying MODPAT = 3 and supplying the modules (routines) needed to calculate the performance of the modem.

2.2 DATA INPUT AND CHECKING

The data which specify the parameters of the link to be evaluated are input from a disk file. The file must have a specific format, described in Section 3.2 and illustrated by examples in Section 4.

The input file is processed line by line (subroutine INDATA) with checking for possible errors (subroutine CHKDAT)

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* Fade outage is defined as a short term fade ($\lesssim$1 second) below an instantaneous bit error rate (BER) threshold (e.g., 10(-3),10(-4) or 10(-5)).

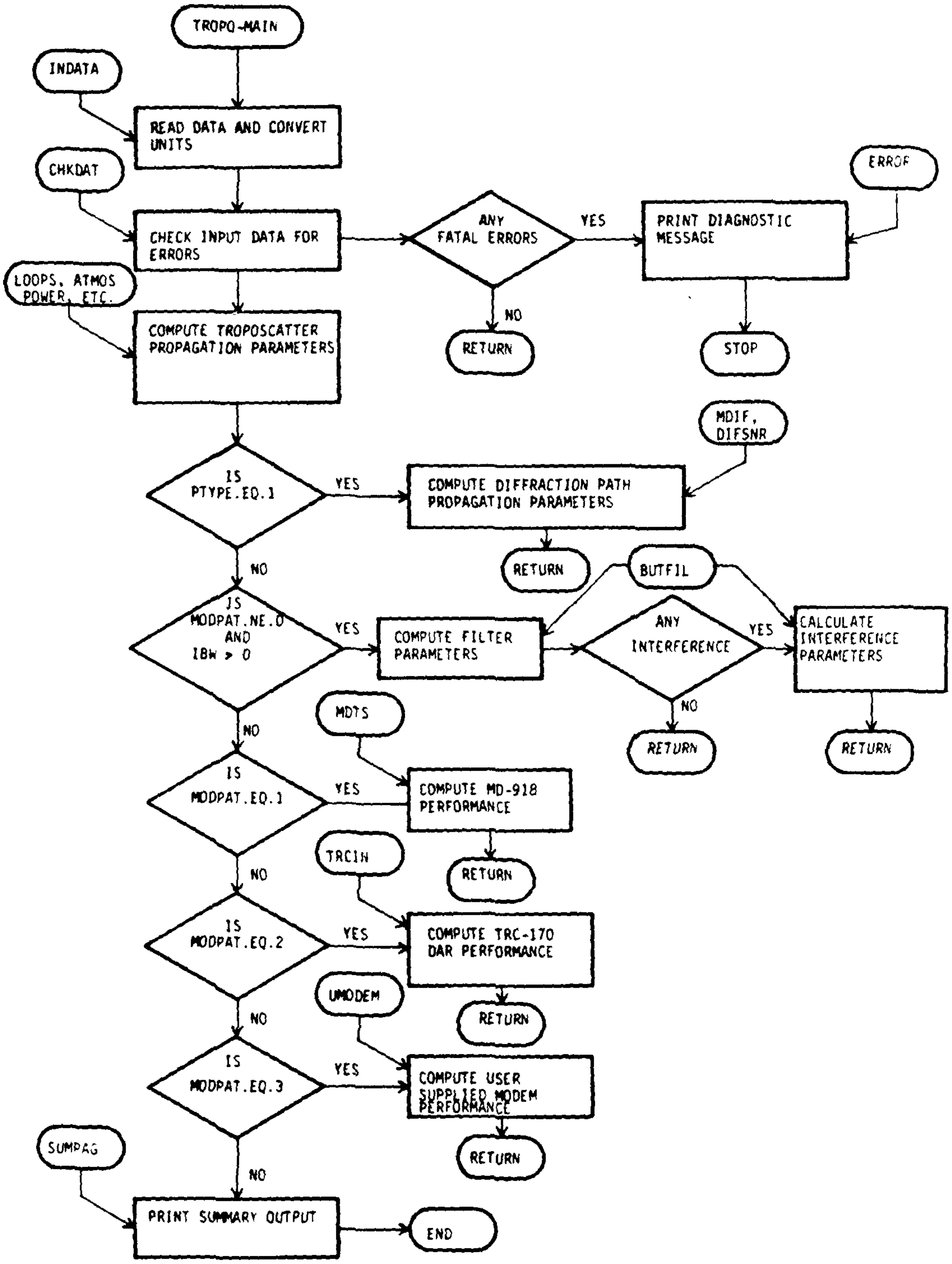

Figure 2-1 Top Level Functional Flow Chart for TROPO Program Calculations

SECTION 2

OVERVIEW OF TROPO PROGRAM CALCULATIONS

In this section we present a top level description of the TROPO computer program, so that the user will have some understanding of what goes on during a typical run. The treatment here includes a description of the main calculations performed by the TROPO Program in order to assist the user with the interpretation of the output. Users wishing to obtain a more detailed understanding of the theory behind TROPO are referred to the Final Report on this project and the references listed therein. For a detailed description of the structure and logical organization of TROPO software, the user is referred to the software documentation report.

Figure 2-1 is a top level flowchart of the TROPO computer program at a functional level. The blocks of Figure 2-1 typically correspond to one or more modules (subroutines). The functions performed by these blocks are described below. Not shown is the detailed Path/Modem output, which is to unit LOUT. Output to this unit occurs from various program modules, including tropo and diffraction calculation modules and the modem evaluation routines.

2.1 MAIN PROGRAM FUNCTIONS

The routines in TROPO can be grouped into nine major functions performed by the program: (1) data input and unit conversion, (2) data checking, and error diagnostics; (3) troposcatter propagation mode parameter calculations; (4) diffraction mode propagation parameter calculations; (5) climate variability calculations; (6) transmitter and receiver filter parameter calculations; (7) MD-918 modem performance calculations; (8) AN/TRC-170-DAR Modem performance calculations; and (9) summary output data.

		UCV	NBS	MIL	UAV	TRO	MIX	HEA	EAH	ATE	LL	99	FCC	JAM	MSEP	ADIV	SDIV	FDIV	8DIV	MD918	TRC170	UMODEM
Unit Conversion	(UCV)																					
NBS Climates	(NBS)																					
MIL-HBK Climates	(MIL)																					
User-def. Availability	(UAV)																					
Tropo Path Model	(TRO)																					
Mixed Tropo/Diffraction	(MIX)																					
Horizon Elevation Angles	(HEA)																					
Effective Antenna Height	(EAH)																					
Avg. Terrain Elevation	(ATE)																					
Lineloss Specification	(LL)																					
99% Power BW Spec.	(99)																					
FCC BW Spec.	(FCC)																					
Jamming/Interference	(JAM)						X															
Correl. BW & Min. Sep.	(MSEP)																					
Space/Angle Diversity 2S/2A	(ADIV)													X								
Quad Space Diversity 2S/2P	(SDIV)													X								
Space/Frequency Diversity 2S/2F	(FDIV)																					
8th-Order Diversity	(8DIV)						X							X								
MD-918 Modem	(MD918)													*								
AN/TRC-170 Modem	(TRC170)						X									X	X		X	X		
User-defined Modem	(UMODEM)																					

*dual space/dual frequency diversity (2S/2F) only

Table 1-1 Tropo Function Exclusion Matrix

used, the climate dependent median correction factor and variability about the median are no longer applicable, unless the structure constant height profile happens to correspond to mid winter afternoon conditions in continental temperate climates.

TROPO has been implemented for both PDP-11/70 and IBM-370 operating environments. Since it has been written in FORTRAN with some attention to portability, it can be adapted to other systems with little difficulty provided that they support FORTRAN IV.

Although TROPO permits a wide variety of options, certain combinations of operations are mutually incompatible in the present version. Table 1-1 summarizes the combinations that are excluded.

(3) The program supports both metric and English units of distance and both degrees and milliradians as units of angle.

(4) The program computes and prints out the correlation (coherence) bandwidth of the troposcatter propagation path and the minimum recommended frequency separation for frequency diversity applications.

(5) Simplified data input formats are available for standard diversity configurations such as dual space/dual frequency (2S/2F), dual space/dual angle (2S/2A) and dual space/dual polarization, (also referred to as quad space) (2S/2P) diversity.

(6) The propagation model will accept any user-defined diversity configuration that is symmetric about the great circle plane, provided the number of diversities does not exceed the value (currently 4) for which all arrays are dimensioned.

(7) The program accepts path profiles of terrain elevation data for accurate troposcatter and/or diffraction path loss calculations, as well as calculating horizon elevation angles, effective antenna heights and average terrain elevation.

(8) The default height profile of the atmospheric turbulence structure constant C_n^2 parameter can be replaced by a user-defined profile. However when a user defined structure constant profile is

radius of 4/3 corresponds to the median of the monthly mean refractivity at sea level SEAN, not the minimum monthly mean surface refractivity relative to which $V(d_e)$ is defined. However, a study of the dependence of the troposcatter path loss on the effective earth radius factor (see Figure 2-4) for a typical 100 mile link (all other conditions being equal) reveals that there is little variation (less than 1 dB) of the path loss for values of ERFAC between 1 and 2 which correspond to typical ranges in the refractivity gradients between -80 N-units/km and 0 N-units/km. Certainly the range of variation in the path loss with changes in the effective earth radius (and hence the surface refractivity N_S) is much smaller than the median correction factor, $V(d_e)$, which can be as large as ±8 dB for some climates.

These arguments lead us to conclude that for troposcatter paths the correction factor, $V(d_e)$, accounts for effects other than variations in monthly mean refractivity at sea level (or equivalently the effective earth radius factor).* In fact most of the variability in the troposcatter signal is caused by changes in the humidity and temperature within the common volume which affect the fraction of power scattered towards the receiver.

The reference troposcatter path loss is calculated from numerical evaluation of the triple integral (subroutine LOOPS)

$$P_R = P_T G_T G_R A_b \iiint C(m) \frac{|g_T(\underline{r})\ g_R(\underline{r})|^2}{R_T^2(\underline{r})\ R_R^2(\underline{r})} \Theta(\underline{r})^{-m} dV \qquad (2.8)$$

* This is not true for diffraction paths however as seen from the curves of Figure 2-4.

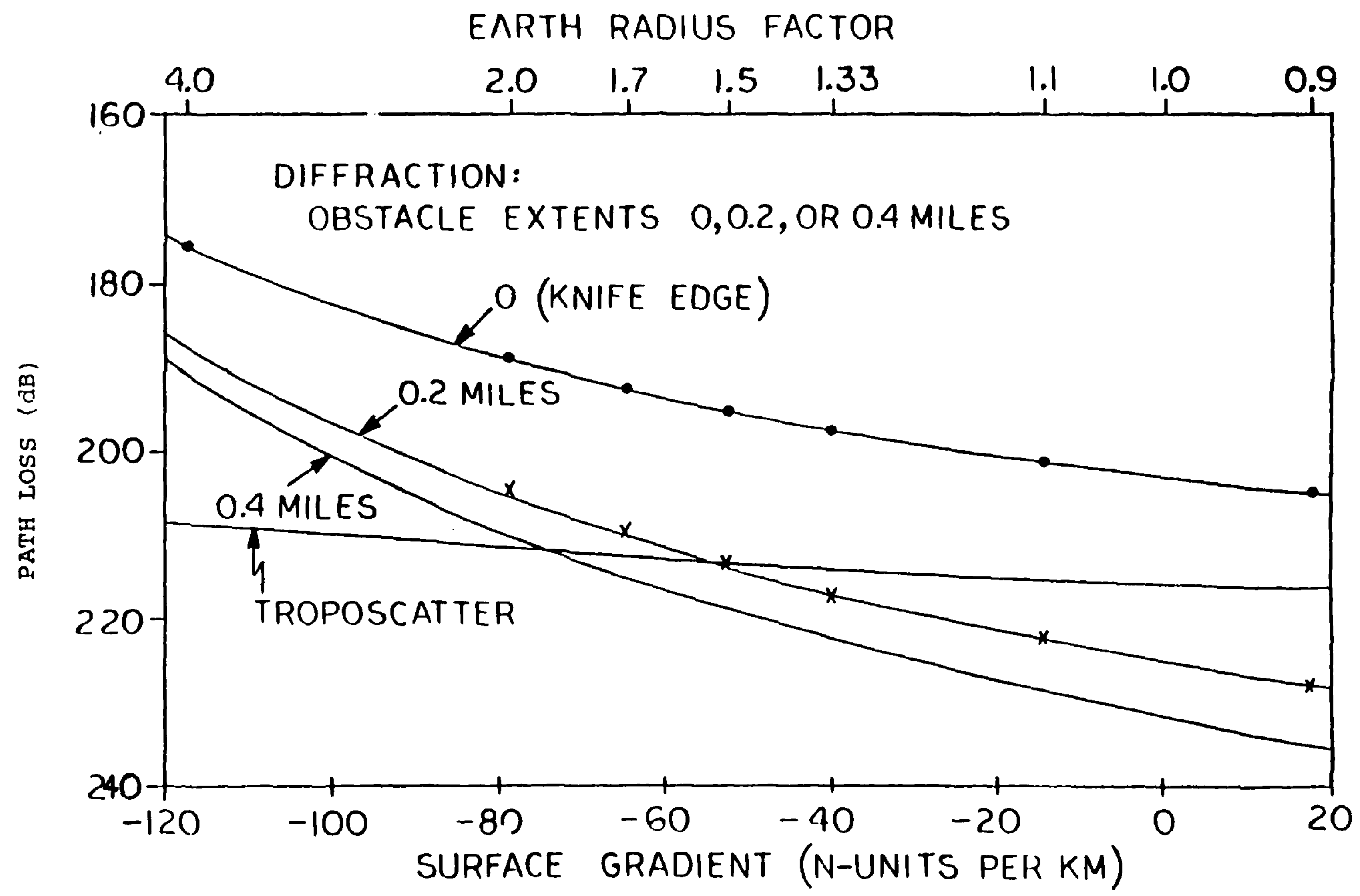

Figure 2-4 Predicted Troposcatter and Diffraction Path Losses on Jackson Butte-Stanford Link

where

P_R	=	received power (Watts),
P_T	=	transmitted power (Watts) (coded WLT)
G_T, G_R	=	transmit and receive antenna gain on boresight (dimensionless ratio),
g_T, g_R	=	transmit and receive antenna voltage gain patterns normalized to unity gain (calculated by functions TGAIN and RGAIN)
R_T, R_r	=	distances from transmitter and receiver to the point $\underline{r}$ in the common volume,
$\Theta(\underline{r})$	=	scattering angle at the point $\underline{r}$ in the scattering volume,
m	=	wavenumber spectrum slope of refractive index fluctuations (determines dependence of the scattering cross section on the scattering angle) (coded SCPARM),
C(m)	=	a proportionality constant which depends on frequency, height of the scattering volume and the choice of the wavenumber spectrum slope,
A_b	=	atmospheric attenuation due to oxygen and water vapor absorption (coded AA),
L_r	=	$P_T G_T G_R / P_r$ (dimensionless reference path loss).

The integrand of the triple integral in (2.8) is negligible outside the common volume intersected by the transmit and receive antenna patterns, g_T and g_R. Hence (2.8) includes the aperture-to-medium coupling loss.

2.5.2.1 Antenna Patterns

The gain and directional voltage pattern of the transmit and receive antennas are computed (subroutine ANTPAR) from the operating frequency and antenna diameter, assuming that each antenna is a parabolic dish with 65% area efficiency.

The gain is computed as

$$G = 6.4\ (D/\lambda)^2 \tag{2.9}$$

where D is the antenna diameter and λ is the wavelength. The voltage gain pattern (calculated in GPATT) is assumed to be of the form

$$g(\phi) = \frac{2J_1(a \sin \phi)}{a \sin \phi} \tag{2.10}$$

where $J_1(x)$ is the first order Bessel function of the first kind, ϕ is the off-boresight angle, and

$$a = \frac{\pi D}{1.2\lambda} \quad . \tag{2.11}$$

The 3 dB beamwidth is calculated from

$$\phi_3 = 1.22(\lambda/D). \tag{2.12}$$

2.5.2.2 Common Volume Geometry

The geometry and boundaries of the common volume are then determined from the intersection of the transmit and receive antenna patterns. First, a modified form of the effective Earth's radius transformation is performed in subroutine TRANSF. When the refractivity of sea level is not specified (SEAN = 0), the effective earth radius factor ERFAC specified in the input file is used; otherwise ERFAC is calculated from the specified refractivity SEAN and this value of ERFAC is used instead of the value in the input file. The effective earth radius accounts for the mean curvature of the beams due to atmospheric refraction. In the transformed coordinate system, the beams follow straight lines, simplifying the calculation of the region of intersection ("common volume").

Using the calculated patterns as well as the assumed dependence of the scattering cross section upon scattering angle, the limits of integration to be used in the propagation calculations are determined (subroutine INTLIM). Points which are outside the 3-dB beamwidth, or which involve such a large scattering angle that their contribution would be negligible, delimit the preliminary bounds on the integration. From these bounds, and the input parameter ERR, the integration step size is determined. A typical value of ERR is 0.001. The integration is terminated when the contribution to the integral falls below a number proportional to 1/NACCU. Typically NACCU = 30-500 is used. During familiarization with the program a new user should determine the effect of these accuracy parameters by typing several values and comparing the results. Decreasing ERR and/or increasing NDELB improves accuracy at the expense of increased computation time.

2.5.2.3 Atmospheric Structure Constant and Spectrum Slope

The scattering angle and frequency dependence of the troposcatter path loss depend on the choice of the slope m (coded SCPARM) of the wavenumber spectrum of the atmospheric refractive index fluctuations (turbulence).

The frequency dependence is found from the definition of C(m), i.e.,

$$C(m) = C_N^2 \, r_0^{11/3-m} \, k^{2-m} \, \frac{\Gamma(m/2)}{2\sqrt{\pi}\, \Gamma\left(\frac{m-3}{2}\right)} \cdot \frac{\Gamma(4/3)}{2^{1/3}\Gamma(2/3)} \qquad (2.13)$$

where $k = 2\pi/\lambda = 2\pi f/c$, f is the frequency, λ is the wavelength, c is the speed of light, C_N^2 is the 'structure constant' (dimensions of meters to the $-2/3$ power and coded CN2 (•)) of the turbulence when the spectrum slope is $m = 11/3$ (it is a measure of the 'strength' of the refractive index fluctuations and their 'size'), $\Gamma(X)$ is the Gamma function and r_0 is a constant with dimensions of length to be determined later.

The scattering angle dependence can be found by noting that the reference path loss, L_r, can be expressed as the product of the path loss assuming isotropic antenna patterns also called the basic path loss, L_b, and a factor called the aperture-to-medium coupling loss, L_c, which accounts for the additional loss due to the fact that a non-isotropic antenna does not illuminate all the the potential scatterers in the atmosphere.

When the antenna patterns are assumed to be isotropic (i.e., $g_T = g_r = 1$), the triple integral in (2.8) can be evaluated analytically to obtain the following expression for the basic path loss [Parl, 1979]

$$\frac{1}{L_b} = C_N^2 \, r_0^{11/3-m} \, (k\Theta_S)^{2-m} \, \frac{m-3}{4(m-1)(m-2)d} \cdot \frac{\Gamma(4/3)}{2^{1/3}\Gamma(2/3)} \qquad (2.14)$$

where Θ_S is the (minimum) scattering angle at the bottom of the common volume, and d (coded D) is the great-circle path length. This expression shows that the basic path loss has identical frequency and scattering angle dependence, i.e.,

$$L_b \sim (f\Theta_s)^{m-2} \quad . \qquad (2.15)$$

Experimental evidence [Tatarskii, 1971; Gossard, 1977] indicates that the slope m of the refractive index frequency (or wavenumber) spectrum at microwave frequencies is m = 11/3. The NBS Tech Note 101 model, however, predicts a cubic dependence on frequency and scattering angle, i.e., m = 5. The cubic type of frequency and scattering angle dependence may be justifiable at frequencies below 1 GHz (UHF and VHF) where the troposcatter signal is a combination of specular reflections and turbulent scatter [Rottger, 1980].

Since the reference path loss is the median path loss in continental temperate climates during periods of weak signal strength (winter afternoons). We use a conservative model for the structure constant C_N^2 . This constant completely determines the reference path loss when $m = 11/3$ and is given by [Fried, 1967]

$$C_N^2 = 8 \times 10^{-14} \, h^{-1/3} \exp(-h/3200) \qquad (2.16)$$

where h is the height of a scatter within the common volume above the surface of the earth in meters. This model assumes very dry weather conditions and it may be too pessimistic an estimate of median conditions encountered in continental temperate and more humid climates. Some short-term measurements of the vertical profile of the structure constant, C_N^2, at a few locations in the U.S. have been published in the literature [Gossard, 1977]. Long-term distributions of C_N^2 at fixed altitudes have also been measured in Colorado [Chadwick and Moran, 1980]. The prediction of the troposcatter signal strength as well as the multipath spread will be greatly improved when long-term measurements of the entire vertical profile of C_N^2 at altitudes between 0-4 Km become available for all climate zones. In the meantime we use the pessimistic, dry weather, model (Equation (2.16)) to calculate the reference path loss (continental temperate climate - winter afternoons). Correction factors to estimate the median path loss in other climates are used based on the NBS 101 or MIL-HDBK-417 guidelines.

The cubic frequency and scattering angle dependence of the NBS Tech Note 101 model can be obtained by specifying an m = 5 (or SCPARM = 5) spectrum slope. The parameter r_0 in (2.14) has been fixed at so that (2.14) will yield the same basic path loss, L_b, as that predicted by NBS Tech Note 101 to within .5 dB. It should, however, be pointed out that the reference path loss, $L_r = L_b L_c$, calculated by the TROPO program for m = 5 may differ from the actual NBS Tech Note 101 prediction by a greater amount because of the manner in which the aperture-to-medium coupling loss, L_c, is calculated. While NBS Tech Note 101 calculates the basic path loss, L_b, and the aperture-to-medium, coupling loss, L_c, separately using semi-empirical formulas, the TROPO program calculates the reference path loss, L_r, directly according to (2.8) which includes both effects directly. The aperture-to-medium coupling loss may be determined from $L_c = L_r/L_b$ where L_r

is given by (2.18) and L_b is the reference path loss calculated by TROPO according to Equation (2.14). Some analytical approximations for the coupling loss may be found in [Parl,1979].

2.5.2.4 Atmospheric Absorption Loss

The loss due to oxygen and water vapor absorption is calculated by subroutine ATMOS. This loss is printed out in the output data file and is negligible at frequencies below 1 GHz but can be significant at frequencies above 5 GHz.

The loss ($1/A_b$) in dB is calculated from

$$-10 \log A_b = (\gamma_0 + \gamma_W)d \tag{2.17}$$

where γ_0 is the specific attenuation (dB/km) of oxygen, γ_W is the specific attenuation of water vapor and d is the path length in km.

The specific attenuation of water vapor is due to both the 22 GHz absorption line and the so called residual absorption. It is given by [Liebe, 1969]

$$\gamma_W = 2.1 \times 10^{-5} f_G^2 + \frac{2.69 \times 10^{-3} f_G^2}{9 + (f_G - 22.235)^2} + \frac{2.69 \times 10^{-3} f_G^2}{9 + (f_G + 22.235)^2} \tag{2.18}$$

where f_G is the frequency in GHz.

The specific attenuation of oxygen is due to the 60 GHz absorption line and is calculated from

$$\gamma_0 = \frac{6.4 \times 10^{-3} f_G^2}{f_G^2 + .32} + \frac{1.9 \times 10^{-2} f_G^2}{5.07 + (f_G - 60)^2} + \frac{1.9 \times 10^{-2} f_G^2}{5.07 + (f_G + 60)^2} \quad . \tag{2.19}$$

This form of the specific attenuation of oxygen is similar to that proposed by Van Vleck [1947]. The line width's and line strengths have been chosen to give a good fit to the curves of specific attenuation of oxygen published by CCIR [1978] for frequencies up to 35 GHz. TROPO will give an warning message when the specified frequency is greater than this upper limit.

The absorption loss calculation (2.17) assumes the specific attenuation of water vapor and oxygen do not vary significantly with altitude. This is only true for short paths. Therefore TROPO will give a warning message when path lengths greater than 500 km are specified. This limitation could be relaxed by using an effective distance in (2.17), such as those presented graphically in NBS 101, rather than the true distance.

2.5.3 The Median Correction Factors

The long-term reference path loss, L_r, is the median path loss in continental temperate climates during winter afternoons (time block 2). The correction factor $V(d_e)$ accounts for differences between yearly median meteorological conditions in a given climate zone and those existing during winter afternoons in continental temperate climates. The program calculates the appropriate median correction factor for the climate zone specified by the user. The user can select one of eight climate zones defined in NBS Tech Note 101 (ICLIME = 0) [P.L. Rice, et al., 1967]: (1) continental temperate, (2) maritime temperate overland, (3) maritime temperate over sea, (4) maritime subtropical over land, (5) continental temperate time block 2 (winter after-

noons), (6) desert, Sahara, (7) equatorial, and (8) continental subtropical. The user also select one of nine climate zones defined in MIL-HDBK-417 (ICLIME = 1): (1) continental temperate, (2) maritime temperate over land, (3) maritime temperate over sea, (4) maritime subtropical, (5) desert, Sahara, (6) equatorial, (7) continental subtropical, (8) mediterranean, and (9) polar. The user can also specify his own climate zone (ICLIME = 2). However in this case it is assumed that no median correction factor is needed (i.e., $V(d_e) = 0$). Curves of the median correction factor as a function of the effective distance parameter d_e for each of the climate zones defined above may be found in the appropriate references mentioned earlier.

2.5.3.1 Median Correction for NBS Climates

The median correction factor $V(d_e)$ for all climate zones except for continental temperate, maritime temperate overland and maritime temperate oversea is calculated from the analytic representation

$$V(d_e) = [c_1 d_e^{n_1} - f_2(d_e)] e^{-c_3 d_e^{n_3}} \tag{2.20a}$$

$$f_2(d_e) = f_8 + (f_m - f_8) e^{-c_2 d_e^{n_3}} \tag{2.20b}$$

where the values of the coefficients c_1, c_2 and c_3, exponents n_1, n_2, and n_3 and limiting values f_8 and f_m are given in Table 2-1. The median correction factor for continental temperate time block 2 is zero by definition as this is reference time/climate. The median correction factor for continental temperate, maritime temperate overland and maritime time temperate oversea are calculated by interpolating between points tabulated at 50 km

Table 2-1

Constants for Calculation of $V(d_e)$ for NBS Climates

CLIMATE	c_1	c_2	c_3	n_1	n_2	n_3	f_m	f_8
1. Continental Temperate	Interpolation							
2. Maritime Temperate Overland	Interpolation							
3. Maritime Temperate Oversea	Interpolation							
4. Maritime Subtropical	1.09×10^{-4}	5.89×10^{-8}	2.21×10^{-7}	2.06	6.81	2.97	5.8	2.2
5. Continental Temperate Time Block 2	0	0	0	0	0	0	0	0
6. Desert Sahara	-8.85×10^{-7}	2.76×10^{-4}	2.25×10^{-12}	2.8	4.82	4.78	-8.4	-8.2
7. Equatorial	3.45×10^{-7}	3.74×10^{-12}	6.97×10^{-8}	2.97	4.43	3.14	1.2	8.4
8. Continental Subtropical	1.59×10^{-5}	1.56×10^{-11}	2.77×10^{-8}	2.32	4.08	3.25	3.9	0

intervals. The reason for this is that the values of c_1, c_2, c_3, n_1, n_2, n_3, f_m and f_8 given in Tech Note 101 do not reproduce the curves plotted in the same reference.

2.5.3.2 Median Correction for MIL-HDBK 417 Climates

The median correction factor $V(d_e)$ for all Mil-Handbook 417 climate zones except mediterranean is calculated using the analytic representation of Equation (2.20). The values of the constants c_1, c_2, c_3, n_1, n_2, n_3, f_m and f_8 are given in Table 2-2 for each climate zone. The correction for mediterranean climates is calculated as the average of the correction factors for maritime temperate oversea and maritime subtropical.

2.5.4 Variability About the Median

The variability about the median, $Y_0(q)$, also depends on the climate zone, frequency and effective distance parameter d_e. It can be written as

$$Y_0(q) = g(q,f)\ Y(q,d_e) \tag{2.21}$$

where $Y(q,d_e)$ is the variability at a reference frequency and $g(q,f)$ is a correction factor for frequencies other than the reference.

Curves of $Y(q,d_e)$ as a function of the effective distance parameter for each of the NBS Tech Note 101 and MIL-HDBK-417 can be found in these references. The reference frequency for both the NBS Tech Note 101 and MIL-HDBK-417 climates is 1 GHz for all climates except the NBS Tech Note 101 continental temperate, and continental temperate time block 2 (winter afternoons) for which the reference frequency is 100 MHz. There is no frequency correction factor (i.e., $g(q,f) = 1$) for the following NBS climates:

Table 2.2

Constants for Calculation of $V(d_e)$ for MIL-Handbook 417 Climates

CLIMATE	c_1	c_2	c_3	n_1	n_2	n_3	f_m	f_8
1. Continental Temperate	1.59×10^{-5}	1.56×10^{-11}	2.685×10^{-5}	2.32	4.08	2.0	4.2	2.0
2. Maritime Temperate Overland	1.12×10^{-4}	1.26×10^{-20}	1.17×10^{-11}	1.68	7.30	4.41	2.05	2.0
3. Maritime Temperate Oversea	1.09×10^{-4}	2.31×10^{-15}	3.82×10^{-9}	2.06	5.50	3.75	6.8	3.6
4. Maritime Subtropical	1.09×10^{-4}	1.02×10^{-13}	2.21×10^{-7}	2.06	5.0	2.97	6.2	1.5
5. Desert Sahara	-4.79×10^{-9}	5.93×10^{-7}	5.14×10^{-15}	3.67	2.41	6.21	-4.8	-8.8
6. Equatorial	9.79×10^{-17}	3.8×10^{-7}	6.97×10^{-8}	7.21	3.18	3.14	2.0	-8.8
7. Continental Subtropical	1.59×10^{-5}	1.56×10^{-5}	2.685×10^{-5}	2.32	4.08	2.0	4.2	2.0
8. Mediterranean	Average of 3 and 4							
9. Polar	Same as for Continental Temperate							

.4.7 Effective Antenna Height

The calculation of the effective distance parameter d_e re-
res that the effective antenna heights, h_{te} and h_{re}, be either
culated by the program (NTERR = 1,2) or supplied by the user
ERR = 0).

The effective transmit and receive antenna heights* are
ined as

$$
\begin{aligned}
HTE &= HT + HT0 - AVETX \\
HRE &= HR + HR0 - AVERX
\end{aligned}
\tag{2.36}
$$

ere HT (HR) is the transmit (receive) antenna height above
ound, HT0 (HR0) is terrain elevation above sea level at the
ansmit (receive) antenna site, and AVETX (AVERX) is the average
eground terrain elevation above sea level at the transmit
eceive) antenna site. The user can choose to specify HT, HT0
AVETX and HR, HR0 and AVERX (if NTERR = 1) for the calcula-
on of the effective transmit and receive antenna heights or he
have the program calculate the average terrain elevation
TX and AVERX (when NTERR = 2) from terrain elevation data he
plied.

The average foreground terrain elevation AVETX (or AVERX)
calculated by fitting a curve of the form

NOTE: These effective antenna heights are relative to average terrain elevation and should not be confused with effective heights above sea level which are used to take into account ray bending effects on the scattering angle. The latter are defined in Appendix B.1.

The remaining parameter d_{S1} is the distance at which diffraction and forward-scatter losses are approximately equal over a smooth earth of effective radius R_e = 9000 km so that

$$d_{S1} = 9000\ \theta_{A1} = 65(100/f)^{1/3} \tag{2.35}$$

where f is the frequency in MHz.

This definition of the effective distance parameter indicates that a great deal of the variability in over-the-horizon propagation at microwave frequencies is caused by mixed troposcatter-diffraction propagation and that the median correction and variability curves for the climate types defined in NBS Tech Note 101 and MIL-HDBK-417 take mixed propagation conditions into account. This is perfectly satisfactory for narrowband systems where any delay differences between the troposcatter and diffraction signals are negligible. However this is not necessarily the case for high data rate digital communications systems where the delay difference between the troposcatter and diffraction signals may exceed the symbol duration. In order to avoid this problem, the TROPO program has the flexibility of calculating the medians of the troposcatter and diffraction signals explicitly if the user chooses to specify mixed-mode propagation conditions (PTYPE = 1). The program also calculates the variability of each of these modes about their respective medians according to the methods recommended in NBS Tech Note 101 and/or MIL-HDBK-417. However one has to reconsider the applicability of the median correction factors and variability curves when troposcatter and diffraction distributions are calculated explicitly (i.e., separately). In this case, it is likely that the NBS Tech Note 101 and MIL-HDBK-417 variability curves will overestimate the variability of the individual troposcatter and diffraction modes.

and

$$
\begin{aligned}
Y_0(10) &= -Y_0(90) \\
Y_0(1) &= 2.0\ Y_0(10) \\
Y_0(.1) &= 2.73\ Y_0(10) \\
Y_0(0.1) &= 3.33\ Y_0(10).
\end{aligned}
\tag{2.32b}
$$

These relationships between $Y_0(q)$ and $Y_0(90)$ and $Y_0(10)$ are also used in the NBS Tech Note 101 climates. Somewhat different proportionality constants for the low percentile events are used in the MIL-HDBK-417 climates. They are climate zone dependent.

2.5.4.6 Effective Distance Parameter

The parameter d_e used for calculating the median correction factor $V(d_e)$ and the variability about the median $Y(d_e)$ is a function of the effective antenna height and frequency. It is defined as [P.L. Rice, et al., 1967]

$$
d_e = \begin{cases} 130\ d/(d_L + d_{S1}) & \text{km, if } d < d_L + d_{S_1} \\ 130 + d - (d_L + d_{S1})\text{km,} & \text{if } d > d_L + d_{S_1} \end{cases} \tag{2.33}
$$

where d is the great circle path length, and d_L is the sum of the effective transmitter and receiver radio horizon distances, i.e.,

$$
d_L = 3\sqrt{2h_{te}} + 3\sqrt{2h_{re}} \quad \text{km} \tag{2.34}
$$

with the effective antenna heights h_{te} and h_{re} in meters.

2.5.4.5 User Specified Climate Variability

When the user specifies his own climate type (ICLIME = 2) the TROPO program calculates $Y_0(90) = g(f)\ Y(90,d_e)$ from the following input values supplied by the user: (a) the value $Y(90,d_e = 0)$, (b) the value of $d_e = d_{min}$ at which $Y(90, d_{min})$ has its minimum value, (c) the absolute value of $Y(90, d_{min})$, (d) the value $Y900 = Y(90,d_e > 900\ \text{km})$, and (e) the frequency correction factor $g(f)$ if other than its default value of one.

The program computes the coefficients of a curve of the form

$$-Y(90,d_e) = \begin{cases} c_0 + c_1 d_e^2 \exp(-\alpha\ d_e^2) & , d_e < 1.316\ d_{min} \\ c_f + c_2 \exp(-\beta d_e) & , d_e > 1.316\ d_{min} \end{cases} \qquad (2.31)$$

and prints out the values of c_0, c_1, c_2, c_f, α and β which fit the data supplied by the user. This curve is similar to that used in NBS Tech Note 101 except that the NBS coefficients n_1, n_2 and n_3 have been fixed, i.e., $n_1 = n_3 = 2$ and $n_2 = 1$. The reason for fixing these coefficients is that only four independent coefficients can be computed from the data supplied by the user. Nonetheless, a curve of this type will provide a good fit to all $Y(90,d_e)$ curves for the NBS Tech Note 101 and MIL-HDBK-417 curves.

The variability at other percentiles is calculated from

$$\begin{aligned} Y_0(99) &= 1.82\ Y_0(90) \\ Y_0(99.9) &= 2.41\ Y_0(90) \\ Y_0(99.99) &= 2.9\ Y_0(90) \end{aligned} \qquad (2.32a)$$

where

$$X_0 = 5.473 \log_{10}(f_{MHz}/215) \quad . \tag{2.29b}$$

The correction factor for the continental temperate climate only and percentiles q > 50 is calculated from

$$g(q > 50, f) = \begin{cases} 1.045 + .075 \sin(X_0), & 150 \text{ MHz} < f < 1.5 \text{ GHz} \\ .97 & , f > 1.5 \text{ GHz} \end{cases} \tag{2.29c}$$

The correction factor for continental subtropical and desert (Sahara) climates and percentiles q > 50 is equal to unity. However the correction factor for desert (Sahara) climates and percentiles q < 50 is approximated by

$$g(q < 50, f) = \begin{cases} 1.07 + .1 \sin(X_0), & 150 \text{ MHz} < f < 1.5 \text{ GHz} \\ .97 & , f > 1.5 \text{ GHz} \end{cases} \quad . \tag{2.30}$$

The lowest frequency of applicability for the MIL-HDBK-417 climate frequency correction factors approximations is 150 MHz.

Table 2-7

Constants for Calculation of $-Y(90,d_e)$ for MIL-Handbook 417 Climates

CLIMATE	c_1	c_2	c_f	β	d_m	d_c
1. Continental Temperate	6.29×10^{-4}	22.54	3.5	5.28×10^{-3}	210	250
2. Maritime Temperate Overland	6.53×10^{-4}	88.51	8.8	15.4×10^{-3}	216	250
3. Maritime Temperate Oversea	8.74×10^{-4}	41.18	10.	9.03×10^{-3}	216	250
4. Maritime Subtropical	4.24×10^{-4}	8.65	8.3	2.48×10^{-3}	283	300
5. Desert Sahara	7.69×10^{-4}	42.11	3.6	6.92×10^{-3}	206	260
6. Equatorial	5.9×10^{-4}	25.79	3.5	8.17×10^{-3}	192	235
7. Continental Subtropical	6.8×10^{-4}	33.08	3.2	7.03×10^{-3}	200	250
8. Mediterranean	Average of 3 and 4					
9. Polar	Same as 1					

Table 2-6

Constants for Calculation of $Y(10, d_e)$ for MIL-Handbook 417 Climates

CLIMATE	c_1	c_2	c_f	β	d_m	d_c
1. Continental Temperate	11.48×10^{-4}	27.43	6.	8.03×10^{-3}	170	200
2. Maritime Temperate Overland	6.41×10^{-4}	29.02	10.8	10.94×10^{-3}	233	255
3. Maritime Temperate Oversea	7.95×10^{-4}	35.64	10.8	9.09×10^{-3}	225	255
4. Maritime Subtropical	6.64×10^{-4}	37.90	13.	7.57×10^{-3}	267	300
5. Desert Sahara	12.87×10^{-4}	64.56	6.	9.76×10^{-3}	178	225
6. Equatorial	5.44×10^{-4}	16.12	3.	5.38×10^{-3}	200	235
7. Continental Subtropical	14.16×10^{-4}	49.90	10.	10.48×10^{-3}	178	210
8. Mediterranean	Average of 3 and 4					
9. Polar	Same as 1					

The 10 percentile, $Y(10, d_e)$, and 90 percentile, $Y(90, d_e)$, variability factors are calculated according to the following analytic expression

$$\left.\begin{array}{l} Y(10,\ d_e) \\ -Y(90,\ d_e) \end{array}\right\} = \begin{cases} c_1 d_e^{\,2} e^{-d_e^{\,2}/d_m^{\,2}} & \text{if } d_e \leq d_c \\ c_f + c_2 e^{-\beta d_e} & \text{if } d_e > d_c \end{cases} \tag{2.28}$$

where the constants d_m, d_c, c_1, c_2, c_f and β are climate zone dependent. Table 2-6 gives the constants for the calculation of $Y(10, d_e)$ and Table 2-7 gives the constants for the calculation of $-Y(90, d_e)$.

2.5.4.4 Frequency Correction Factors for MIL-HDBK-417 Climates

Three of the MIL-Handbook 417 climates require correction factors to calculate the path loss distribution at a frequency other than the reference frequency of 1 GHz. These are continental temperate, continental subtropical and desert, Sahara climates. The other climates do not require a frequency correction factor.

The frequency correction factors for the MIL-HDBK-417 climates are different than those for NBS climates. The correction factor for the continental temperate and continental subtropical climates for $q < 50$ is calculated from

$$g(q < 50, f) = \begin{cases} 1.105 + 1.35 \sin(X_0), & 150 \text{ MHz} \leq f \leq 1.5 \text{ GHz} \\ .97 & , f > 1.5 \text{ GHz} \end{cases} \tag{2.29a}$$

Table 2-5

Proportionality Constants for MIL-Handbook 417
Variability Factors

CLIMATE	a_1	a_2	a_3
1. Continental Temperate	3.33	2.73	2.0
2. Maritime Temperate Overland	3.8	3.08	2.2
3. Maritime Temperate Oversea	3.8	3.08	2.2
4. Maritime Subtropical	3.7	3.3	2.22
5. Desert Sahara	2.88	2.4	1.82
6. Equatorial	3.33	2.73	2.0
7. Continental Subtropical	2.64	2.27	1.8
8. Mediterranean	Average of 3 and 4		
9. Polar	Same as 1		

The frequency correction factor for NBS Tech Note 101 desert (Sahara) climate is calculated for all percentiles from

$$g(q,f) = \begin{cases} 1.05 + 0.74 \sin(X) & , 250 \text{ MHz} < f < 2 \text{ GHz} \\ .976 & , f > 2 \text{ GHz} \end{cases} \qquad (2.25)$$

Similarly, the frequency correction factor for NBS Tech Note 101 continental subtropical climate is calculated for all percentiles q from

$$g(q,f) = \begin{cases} 1.082 + .212 \sin(X) & , 200 \text{ MHz} < f < 2 \text{ GHz} \\ .976 & , f > 2 \text{ GHz} \end{cases} \quad . \qquad (2.26)$$

The lowest frequency for which these analytic expressions are good approximations to the correction factors shown graphically in NBS Tech Note 101 [P.L. Rice, et al., 1967] are given next to each expression.

2.5.4.3 Variability for MIL-Handbook 417 Climates

The path loss distribution (variability) about the median at a reference frequency of 1 GHz, $Y(q,d_e)$ is calculated as

$$\begin{aligned} Y(.01, d_e) &= a_1 \, Y(10, d_e) \\ Y(.1, d_e) &= a_2 \, Y(10, d_e) \\ Y(1., d_e) &= a_3 \, Y(10, d_e) \\ Y(99, d_e) &= 1.82 \, Y(90, d_e) \\ Y(99.9, d_e) &= 2.41 \, Y(90, d_e) \\ Y(99.99, d_e) &= 2.9 \, Y(90, d_e) \end{aligned} \qquad (2.27)$$

where the proportionality constants a_1, a_2 and a_3 are climate zone dependent and are given in Table 2-5.

2.5.4.2 Frequency Correction Factors for NBS Climates

Four of the NBS climates require the use of a correction factor to calculate the path loss distribution at a frequency other than the reference frequency. These are continental temperate all year, continental temperate time block 2 (winter afternoons), desert (Sahara) and continental subtropical. There is no frequency correction factor for the other climates.

The frequency correction factors for the continental temperate and continental temperate time block 2 climates for percentiles $q < 50$ are approximated by

$$g(q < 50, f) = \begin{cases} 1.27 + 0.22 \sin(X), & 100\text{ MHz} < f < 2\text{ GHz} \\ 1.05, & f > 2\text{ GHz} \end{cases} \tag{2.23a}$$

and for percentiles $q > 50$ by

$$g(q > 50, f) = \begin{cases} 1.23 + 0.18 \sin(X), & 100\text{ MHz} < f < 2\text{ GHz} \\ 1.05, & f > 2\text{ GHz} \end{cases} \tag{2.23b}$$

where

$$X = 4.495 \log_{10} \left(f_{MHz}/180\right) \tag{2.24}$$

and where f_{MHz} is the frequency in MHz.

Table 2-4

Constants for Calculation of $-Y(90, d_e)$ for NBS Climates

CLIMATE	c_1	c_2	c_3	n_1	n_2	n_3	f_m	f_8
1. Continental Temperate	9.42×10^{-3}	5.7×10^{-11}	5.56×10^{-6}	1.33	3.96	2.44	8.2	3.0
2. Maritime Temperate Overland	Interpolation							
3. Maritime Temperate Oversea	Interpolation							
4. Maritime Subtropical	7.24×10^{-3}	4.26×10^{-15}	1.12×10^{-6}	1.35	5.41	2.56	12.7	8.4
5. Continental Temperate Time Block 2	1.0×10^{-5}	7.0×10^{-13}	7.64×10^{-9}	2.59	4.8	3.68	7.05	2.8
6. Desert Sahara	3.19×10^{-2}	5.66×10^{-8}	7.39×10^{-11}	1.14	2.76	4.4	11.4	3.3
7. Equator'al	6.51×10^{-3}	2.53×10^{-4}	2.61×10^{-16}	1.36	1.36	6.55	8.4	2.7
8. Continental Subtropical	3.49×10^{-3}	1.08×10^{-9}	9.15×10^{-11}	1.55	3.49	4.48	10.1	3.5

Table 2-3

Constants for Calculation of $Y(10, d_e)$ for NBS Climates

CLIMATE	c_1	c_2	c_3	n_1	n_2	n_3	f_m	f_8
1. Continental Temperate	3.56×10^{-2}	9.85×10^{-8}	1.5×10^{-11}	1.13	2.8	4.85	10.5	5.4
2. Maritime Temperate Overland	Interpolation							
3. Maritime Temperate Oversea	Interpolation							
4. Maritime Subtropical	4.33×10^{-2}	7.13×10^{-11}	1.19×10^{-12}	1.09	3.89	4.93	17.5	13.6
5. Continental Temperate Time Block 2	1.04×10^{-5}	4.28×10^{-8}	3.51×10^{-8}	2.71	2.91	3.41	9.15	2.8
6. Desert Sahara	6.02×10^{-2}	1.36×10^{-5}	3.18×10^{-11}	1.08	1.84	4.69	15.1	6.0
7. Equatorial	5.22×10^{-3}	1.57×10^{-4}	5.22×10^{-17}	1.39	1.46	6.78	8.5	3.2
8. Continental Subtropical	1.01×10^{-2}	2.26×10^{-7}	3.9×10^{-9}	1.46	2.67	3.78	16.0	9.1

maritime temperate over land, maritime temperate over sea, maritime subtroptical over land, and equatorial. Similarly there is no frequency correction for the following MIL-HDBK-417 climates: equatorial, maritime subtropical, mediterranean, maritime temperate over land, maritime temperate over sea and polar. Curves for the frequency correction factors for all other climates can be found in the above references. The TROPO computer program uses analytic approximations to these curves.

2.5.4.1 Variability for NBS Climates

The path loss distribution (variability) about the median at a reference frequency of 1 GHz, $Y(q,d_e)$, is calculated as

$$
\begin{aligned}
Y(.01, d_e) &= 3.33\ Y(10, d_e) \\
Y(.1, d_e) &= 2.73\ Y(10, d_e) \\
Y(1., d_e) &= 2.0\ Y(10, d_e) \\
Y(99, d_e) &= 1.82\ Y(90, d_e) \\
Y(99.9, d_e) &= 2.41\ Y(90, d_e) \\
Y(99.99, d_e) &= 2.9\ Y(90, d_e)
\end{aligned}
\tag{2.22}
$$

The 10 percentile, $Y(10, d_e)$, and 90 percentile, $Y(90,d_e)$, variability factors for all NBS climates except maritime temperate overland and maritime temperate oversea are calculated using the analytic expression of Equation (2.20). The constants c_1, c_2, c_3, n_1, n_2, n_3, f_m and f_8 for the calculation of $Y(10,d_e)$ are given in Table 2-3 and the constants for the calculation $-Y(90,d_e)$ are given in Table 2-4. The variability factors for maritime temperate overland and maritime temperate oversea are calculated by interpolating between values tabulated in increments of 50 km.

$$h(X) = \overline{h} + m(X - \overline{X}) \tag{2.37}$$

to NP <u>evenly spaced</u> terrain elevation data points $h_i(X_i)$ between the antenna site and its radio horizon. The point X_1 must be the actual transmit site (or receive antenna radio horizon) while X_{NP} must be the transmit radio horizon (or the receive site).

In order to get a good fit to the terrain data, NP must be greater than 5. The terrain elevation data points near the antenna and its radio horizon are excluded in the calculation of the best fit curve h(x). Thus

$$\overline{h} = \frac{1}{N} \sum_{i=IMIN}^{IMAX} h_i \text{ , } N = IMAX - IMIN$$

$$\overline{X} = \frac{X_1 + X_{NP}}{2} \tag{2.38}$$

$$m = \frac{12}{N(N+1)\left(X_{NP} - X_1\right)} \sum_{i=IMIN}^{IMAX} h_i \left(i - I_0\right), \; I_0 = \frac{N-1}{2}$$

where IMIN and IMAX are chosen so as to exclude the terrain data points nearest the antenna and the radio horizon as follows

$$IMIN = \begin{cases} 2 & \text{if} \quad 5 < NP < 11 \\ 3 & \text{if} \quad 11 < NP < 21 \\ 4 & \text{if} \quad 21 < NP \end{cases} \tag{2.39a}$$

and

$$\mathrm{IMAX} = \begin{cases} \mathrm{NP-1} & \text{if} \quad 5 < \mathrm{NP} < 11 \\ \mathrm{NP-2} & \text{if} \quad 11 < \mathrm{NP} < 21 \\ \mathrm{NP-3} & \text{if} \quad 21 < \mathrm{NP} \end{cases} \quad . \tag{2.39b}$$

The average terrain elevation at the transmit site is then calculated in subroutine AVTER as

$$\mathrm{AVETX} = h(X_1) + m(X_1 - \overline{X}) \tag{2.40}$$

provided that the terrain data supplied is between the transmitter and its radio horizon.

If the terrain data is between the receive radio horizon* and the receive site, then the average terrain elevation at the receive site is calculated as

$$\mathrm{AVERX} = h(X_{NP}) + m(X_{NP} - \overline{X}) \quad . \tag{2.41}$$

The effective antenna heights are then calculated as indicated earlier.

---

* NOTE: Note that the terrain data must be both equidistant and in the proper sequence in order for the above calculations to be valid.

2.5.5 Multipath Spread

The predicted multipath spre·d of the troposcatter signal is calculated simultaneously with the reference path loss calculation, i.e., Equation (2.8) (subroutine LOOPS). This is done by noting that the received power P_r can be written as

$$P_r = \int_{\tau_{min}}^{\tau_{max}} Q(\tau)d\tau \qquad (2.42)$$

where $Q(\tau)$ (coded Q(.,.)) is the received power per unit delay (delay power impulse response profile), τ_{min} is the delay of the path to the lowest point in the scattering volume, and τ_{max} is the delay to the highest point in the scattering volume.

The power per unit delay profile, $Q(\tau)$, is calculated by summing up the contributions to the total received power (see Equation (2.8)) from all those points $\underline{r}$ in the scattering volume with delay

$$\tau = \frac{R_T(\underline{r}) + R_R(\underline{r})}{c} \quad . \qquad (2.43)$$

The rms delay spread (or 2-sigma delay spread) τ_{rms} is then obtained from the definition

$$\tau_{rms}^2 = \frac{4}{P_r} \int_{\tau_{min}}^{\tau_{max}} (\tau - \tau_{AV})^2 \, Q(\tau)d\tau \qquad (2.44)$$

where the average delay τ_{AV} is defined as

$$\tau_{AV} = \frac{1}{P_r} \int_{\tau_{min}}^{\tau_{max}} \tau \, Q(\tau) d\tau \quad . \tag{2.45}$$

The rms delay spreads (or 2-sigma delay spreads) calculated by TROPO are yearly median delay spreads. There is some evidence that the rms multipath spread exhibits long-term variability [Sherwood, et al., 1977]. However the data is not comprehensive enough to establish a correlation between link geometry, climate zone and atmospheric conditions and multipath spread. Nonetheless, the variability of the multipath spread can be sufficiently large that it cannot be ignored.

There are two major mechanisms which can cause variability in multipath spread: one is the variability of the effective earth radius factor (ERFAC) which causes the size of the effective scattering volume (i.e., that part of the common volume which contributes significantly to the total received power) to vary, and the other is variability in the height profile of the atmospheric structure constant C_N^2. There is considerable evidence that significant layering of the turbulence and variability in the layering exists in the atmosphere so that in some cases C_N^2 may actually increase with height within the scattering volume a fraction of the time. In fact this is the only mechanism which can explain the large rms multipath spreads measured on some links [Sherwood, et al., 1977]. The distribution of multipath spread including layering effects has not been modeled yet for lack of information regarding the long-term distribution of C_N^2 as a function of height. Instead TROPO calculates and prints out the maximum delay spread τ_M that can be expected from scatterers within the common volume, i.e.,

$$\tau_M = \tau_{max} - \tau_{min} \approx \frac{d}{2c} \left(\alpha_1 \beta_1 - \alpha_0 \beta_0\right) \tag{2.46}$$

where d is the path length, c is the speed of light, α_0 and α_1 are take-off angles at the transmit site measured from the straight line bisecting the transmitter and receiver to the lowest and highest points in the scattering volume, respectively, and β_0 and β_1 are the corresponding take-off angles at the receive site as shown in Figure 2-5. This is the upper bound on the delay spread of the troposcatter signal*. The value of τ_M is not used in the calculation of MD-918, AN/TRC-170 or DAR Modem performance; only the 2-sigma delay delay spread is used. τ_n is calculated and supplied to the user to warn that this value of multipath spread may occur on the path with some small probability.

2.5.6 Diversity Correlations

The types of diversity correlation calculations performed in TROPO depend on the choice of the parameter DIVTYP. If DIVTYP = 0 is specified, the program assumes a single transmitting antenna and two spaced receiving antennas (Figure 2-6, top), each of which has two angle diversity feeds. The correlation coefficients (short-term Rayleigh fading) and correlation vs. delay profiles for the following diversity configurations are then computed: (a) dual space (2S) diversity, (b) dual space/dual frequency (2S/2F) diversity, (c) dual space/dual angle (2S/2A) diversity, and (d) dual space/dual angle/dual frequency (2S/2A/2F) diversity. If DIVTYP = 1 is selected, the program assumes a single transmitting antenna and a single receiving antenna (Figure 2-6, middle) with two angle diversity feeds. Correlation coefficients and correlation profiles for the following diversity configurations are then calculated: (a) dual angle(2A) diversity,

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* NOTE: This maximum delay spread can only be exceeded whenever strong scatterers, such as airplanes, are within the volume intersected by a sidelobe of one of the antennas.

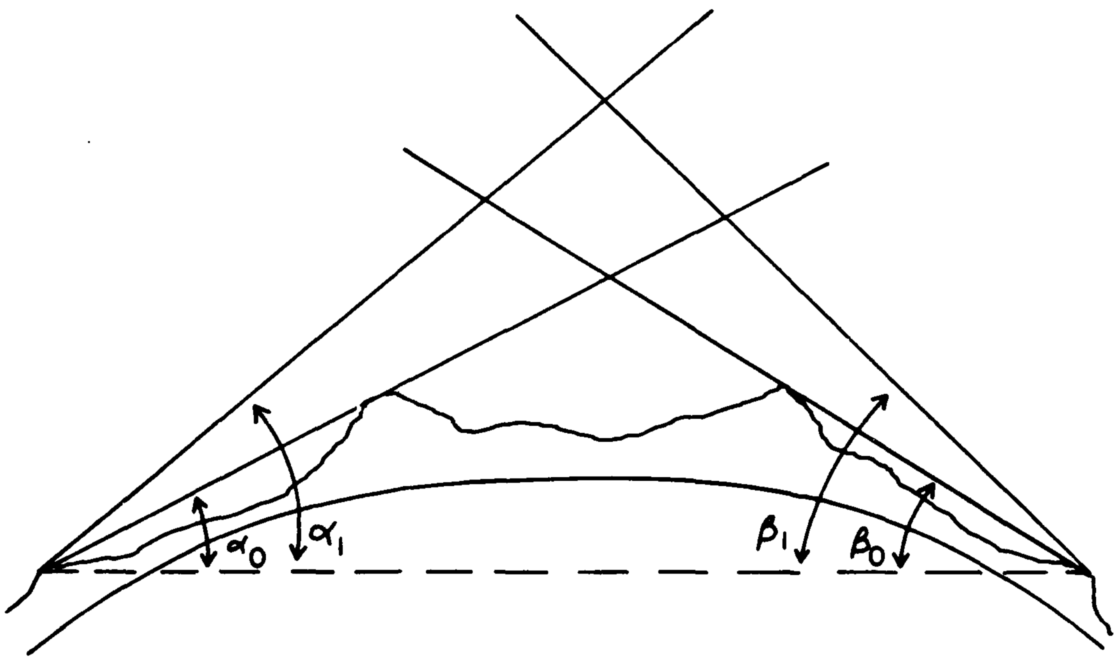

Figure 2-5 Scattering Volume Geometry

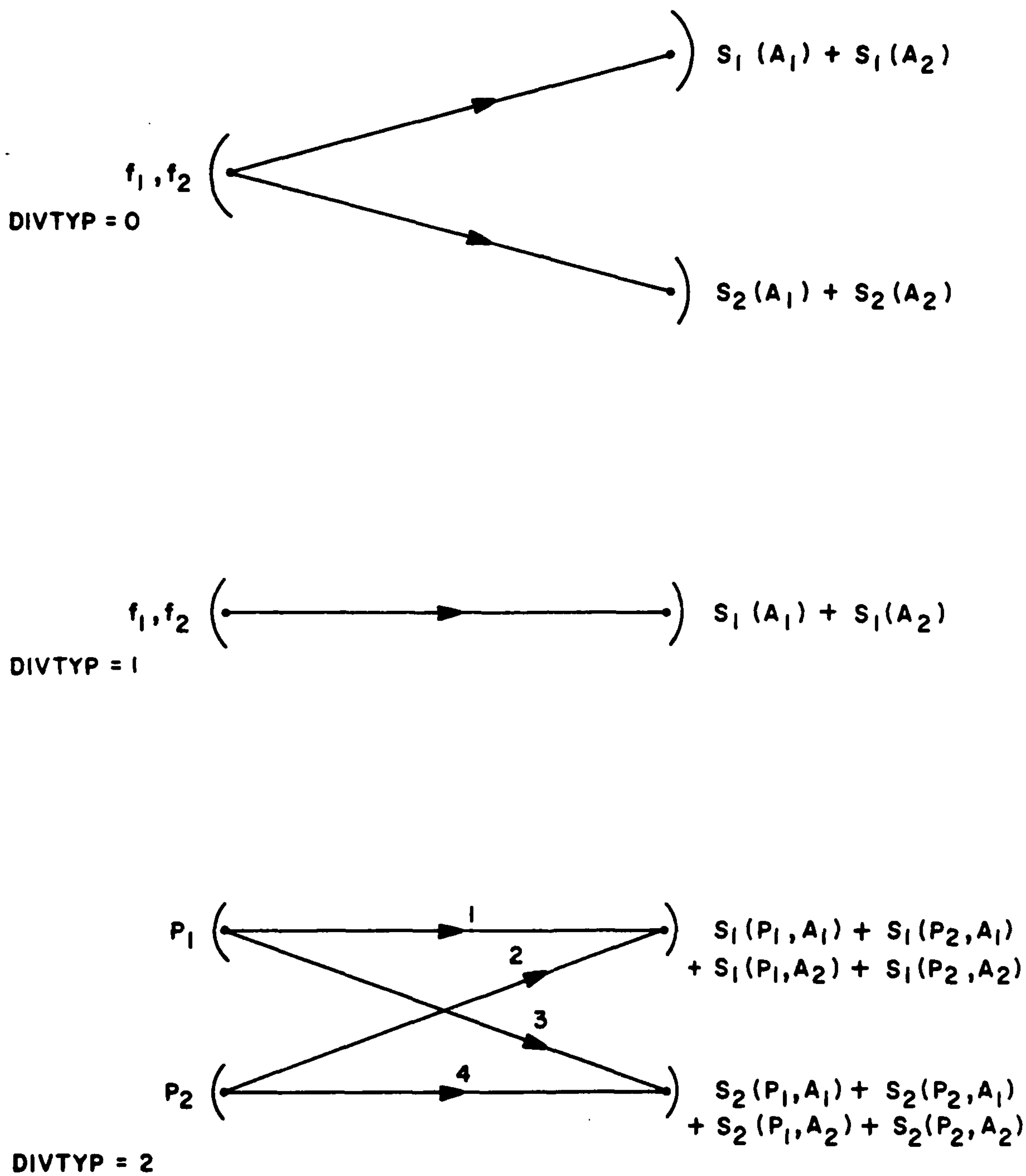

Figure 2-6 Diversity Configurations

(b) dual frequency (2F) diversity and (c) dual frequency/dual angle (2F/2A) diversity. If DIVTYP = 2 is selected, the program assumes two spaced transmitting antennas and two spaced receiving antennas (Figure 2-6, bottom). The two transmitting antennas are assumed to transmit the same information but on orthogonal polarizations. Each of the receiving antennas is assumed to be capable of receiving both polarizations as well as having angle diversity feeds. The correlation coefficients and correlation delay profiles for the following diversity configurations are then computed: (a) dual space/dual polarization (2S/2P) also referred as quadruple space and (b) dual space/dual polarization/dual angle (2S/2P/2A) diversity.*

Table 2-8 summarizes the types of correlation coefficients that are calculated for each of the standard diversity configurations that can be selected by specifying DIVTYP = 0, 1, or 2. Note that there are three types of space diversity correlation coefficients: (a) convergent/divergent path correlation (e.g., the two paths in Figure 2-6, top), (b) cross path correlation (e.g., paths 2 and 3 in Figure 2-6, bottom) and (c) parallel path correlation (e.g., paths 1 and 4 in Figure 2-6, bottom). The angle diversity correlation coefficient is the correlation between the lower and upper beams received at each antenna. The frequency diversity correlation is the correlation between the signals received at two different frequencies. TROPO assumes that when frequency diversity is used, the frequency separation is greater than the coherence bandwidth of the channel so that the frequency diversity correlation coefficient is negligible. The minimum frequency separation required is calculated and supplied in the summary printout SUMPAG.OUT (see parag. 2.5.6.3).

---

* It should be noted that a longer computation time is required for DIVTYP=2. This will be most notable on small computers, i.e., PDP-11/70.

Table 2-8

CORRELATION COEFFICIENTS CALCULATED

DIVERSITY CONFIGURATION	DIVTYP	SPACE DIVERSITY CORRELATION COEFFICIENT			ANGLE DIVERSITY CORRELATION COEFFICIENT	FREQUENCY DIVERSITY CORRELATION COEFFICIENT
		DIVERGENT- OR CONVERGENT PATHS	CROSS PATHS	PARALLEL PATHS		
2S	0	X				
2S/2F	0	X				X
2S/2A	0	X			X	
2S/2A/2F	0	X			X	X
2A	1				X	
2F	1					X
2F/2A	1				X	X
2S/2P	2	X	X	X		
2S/2P/2A	2	X	X	X	X	

Whenever modem performance calculations are desired, the user must specify DIVTYP = 0, 1, or 2. The modem performance for all of the possible diversity configurations (listed above for each value of DIVTYP) is then computed using the correlation coefficients and correlation profiles calculated by TROPO. A non-standard diversity configuration involving more than two antennas at one or both terminals can be specified by the user by selecting DIVTYP = 4. TROPO will then calculate the correlation coefficients specified by the user for the non-standard diversity. However no modem performance calculations are allowed.

The non-standard diversity configuration may consist of one transmitting antenna and up to four spaced receiving apertures.

In addition to specifying the diversity type configuration, i.e., DIVTYP = 0, 1, 2, or 4, the user must specify the center-to-center separation distance betwen the antennas. The antennas may be spaced horizontally (TSEP or RSEP) on the plane perpendicular to the great circle path. This restriction allows TROPO to exploit the symmetry of the configuration to compute a real correlation coefficient. The present version of the program does not allow vertical or combination of vertical and horizontal antenna spacings about the great circle plane because the correlation coefficients would then be complex. The computation time and memory requirements for evaluation of the correlation coefficient (see Equation (2.45) below) using complex notation would be at least double that required for the real case.

2.5.6.1 Space Diversity Correlation Calculations

The correlation coefficient ρ_{12} between the signals received at two spaced antennas (or equivalently the correlation between two signals transmitted using two spaced antennas) is calculated simultaneously with the reference path loss and power

per unit delay calculations (subroutine LOOPS) from the definition

$$\rho_{12} = \frac{P_T G_T G_R A_b}{\sqrt{P_{r1} P_{r2}}} \iiint \frac{C(m) g_{T1}(\underline{r})\ g^*_{T2}(\underline{r})\ g_{R1}(\underline{r})\ g^*_{R2}(\underline{r})}{R^2_T(\underline{r})\ R^2_R(\underline{r})}\ \sigma^{-m} dV \quad (2.47)$$

where P_{r1} is the average power of received signal 1, P_{r2} is the average power of received signal 2, g_{T1} and g_{T2} are the voltage patterns of the transmitting apertures (normalized to unit power gain), and g_{R1} and g_{R2} are the voltage patterns (normalized to unity gain) of the receiving apertures.

Note that if the correlation between the signals received with two spaced receiving apertures is desired, $g_{T1} = g_{T2}$ while the magnitudes of g_{R1} and g_{R2} are also equal. However due to the separation between the receiving apertures the phases of g_{R1} and g_{R2} differ by an amount proportional to the difference in distance from each aperture to the scatterer at a point $\underline{r}$ in the scattering volume which is assumed to be identical for both receiving apertures. The combined effect of the difference in phase path lengths from the two antennas to each element in the common volume is the primary cause of decorrelation between the signals received at two spaced antennas.

2.5.6.2 Angle Diversity Correlation Calculation

The correlation coefficient between two angle diversity signals is also computed using the definition in (2.47). However in this case the two receive antenna patterns illuminate different common volumes. The correlation between the two signals is determined by the amount of overlapping between the two receive antenna patterns.

.5.6.3 Frequency Diversity Correlation and Coherence Bandwidth Calculations

The correlation coefficient $\rho(f_1-f_2)$ between the signals at wo different frequencies f_1 and f_2 is calculated in subroutine 'RQSEP by performing the Fourier transformation

$$\rho(f_1-f_2) = \int_{-\infty}^{\infty} Q(\tau)e^{-j2\pi(f_1-f_2)\tau}\,d\tau \tag{2.48}$$

here $Q(\tau)$ is the power per unit delay function defined in Equa- :ion (2.42) if the two frequencies are transmitted and received ısing the same apertures. If the two frequencies are received on :wo spaced apertures, $Q(\tau)$ is replaced by the cross-correlation lelay profile obtained from (2.47) using similar methods as those ısed in the calculation of the delay power impulse response.

The coherence bandwidth B_c of the channel is determined by searching for the frequency separation f_1-f_2 for which the cor- relation $\rho(f_1-f_2)$ defined in (2.48) is equal to 1/2. The minimum frequency separation FSEP for which two frequency diversity signals are uncorrelated is then defined as

$$FSEP = B_c + BW \tag{2.49}$$

where BW is the bandwidth of the transmitted signal.

2.5.7 Long-Term Variability Correlation Coefficient for Angle Diversity

The correlation coefficients defined in the previous sec- tion are ensemble averages over the short-term Rayleigh fading. The long-term power fading (variability) for the space and fre- quency diversity signals is assumed to be identical, i.e., cor-

relation of unity, since they all share the same scattering volume and hence are all subject to the same long-term fluctuations. The same is not true however for angle diversity signals whose beams illuminate different scattering volumes.

It has been found that the long-term variability about the median for the upper and lower beams in an angle-diversity system is not always perfectly correlated. This is accounted for in TROPO by computing (subroutine LTCORR) an estimate of the correlation coefficient CORRLT for long-term variability as

$$\text{CORRLT} = \exp(\text{HDIF*CONST1})$$

where

HDIF = difference in heigh of bottoms of common volumes for upper and lower beams and CONST1 is an empirical constant.

From CORRLT, a correction factor CORFAC is computed according to

$$\text{CORFAC} = \left(\frac{1 + \text{CORRLT}}{2}\right)^{1/2} \quad . \tag{2.49}$$

This factor is then used multiplicatively to reduce the effective standard deviation of the long-term power fading of the angle diversity beams within the routine BERCAL.

2.6 DIFFRACTION PROPAGATION MODE

When mixed troposcatter-diffraction propagation is specified (PTYPE = 1), the program calculates all of the troposcatter propagation parameters described in Section 2.5 as well as the RSL and path loss yearly distribution of the diffraction signal.

: program also calculates the relative delay between the ·lier arriving diffraction signal and the troposcatter signal. ıever, no correlation calculations are needed because the dif- ıction signal is not a fading signal and hence the diffraction ıponents of the signals received on space diversity antennas : perfectly correlated.

The diffraction path is assumed to be a multiple edge dif- ıction path such as that shown in Figure 2-7. The maximum num- : of edges allowed (NOBS) is three (3). The diffraction loss : paths with more than 3 edges will be much greater than the ɔposcatter loss and hence these paths can be treated as pure ɔposcatter paths. The analytical diffraction model is valid, vever, for an arbitrary number of obstacles (i.e., edges). The stacles can be treated as either knife-edge or rounded edges. :fraction over a smooth or slightly irregular earth can be ɜated as diffraction over a single rounded obstacle. However microwave frequencies the diffraction loss over the bulge of ɜ earth is so large compared to the troposcatter loss that such :hs should be treated as pure troposcatter paths.

To calculate the diffraction path propagation parameters, ɜ user must specify the number of diffracting edges (NOBS), ɜir elevations above sea level (coded HL(1), ..., HL(NOBS)), ɜir distances from the transmitter (coded DL(1), ..., DL(NOBS)) ɹ a parameter called the 'effective horizontal extent' of the stacle (coded DS(1), ..., DS(NOBS)) along the great circle ane which is used to determine whether the obstacle is a knife- ge or a rounded edge. The effective horizontal extent of the stacle is defined as the distance between the points at which ɜ diffraction ray path is tangent to the obstacle. If this stance DS is specified as zero the obstacle is a knife-edge. ɜn DS is not zero, the obstacle is treated as a rounded edge th radius of curvature (coded RC (.) in subroutine MDIF) given

The delay calculation of the diffraction path accounts for e free-space travel time between the transmitter and the stacles and the receiver and does not account for the slower opagation velocity when the signal propagates over a rounded stacle. The latter effect is small relative to the delay difrence between the diffracted signal and the average delay of e troposcatter signal. The average delay of the troposcatter gnal relative to the diffraction path delay is printed out in e summary output.

7 TRANSMITTER AND RECEIVER FILTER CALCULATIONS

TROPO provides the facility for predicting the performance the MD-918 and AN/TRC-170/DAR modems or any user supplied ›dem taking into account the effects of the transmitter and ·ceiver filters. Prior to calculatirg the performance of the)-918 or AN/TRC-170/DAR Modems, TROPO calculates all the transtter and receiver parameters required for the calculation of ıe modem performance in subroutine *BUTFIL.*. *A block diagram of* ıe filter calculations performed is shown in Figure 2-10. Filır calculations are performed only when the parameter IBW > 0.

The transmitter filters for the MD-918 and AN/TRC-170/DAR ›dems consists of the cascade of the intermediate frequency (IF) lter with the baseband pulse shaping filters (rectangular ıpulse response with duration equal to T).* The modem IF output lter is an N-pole Butterworth filter so that the baseband power ›ectrum of the transmitted signal is given by

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NOTE: TROPO only accounts for the IF spectrum constraint filtering in the modem. No degradation effects of radio upconverter/downconverter or Klystron power amplifier nonlinearity are modeled.

(from the first and second edge) or no scattering at all (direct ray). The TROPO program does not consider situations such as this where there is a line-of-sight path.

2.6.3 The Diffraction Path Delay

The delay of the diffraction path $t_r = (d_1+d_2+d_3+...)/c$, where c is the speed of light, is calculated using purely geometric considerations (subroutine MDIF) by summing the lengths of the segments of the ray path the signal must traverse to be diffracted over the obstacles. However in order to avoid round-off errors the delay relative to the slant path (straight line connecting transmitter and receiver) is calculated and this value is printed out along with the short-path delay. More specifically TROPO calculates the distances (See figure 2.9a)

$$S_1 = d_1 + d_2 - d_{02}$$

$$S_2 = d_{02} + d_3 - d_{03}$$

$$\vdots$$

$$S_k = d_{0k} + d_{k+1} - d_{0k+1}$$

where k is the number of edges, d_{0k} is defined as the slant path range and the delay relative to the slant path delay is defined as

$$t_r = \frac{1}{c} \sum_{i=1}^{k} S_k = \frac{1}{c} \left[\sum_{i=1}^{k} d_i - d_{0k+1} \right] . \tag{2.58}$$

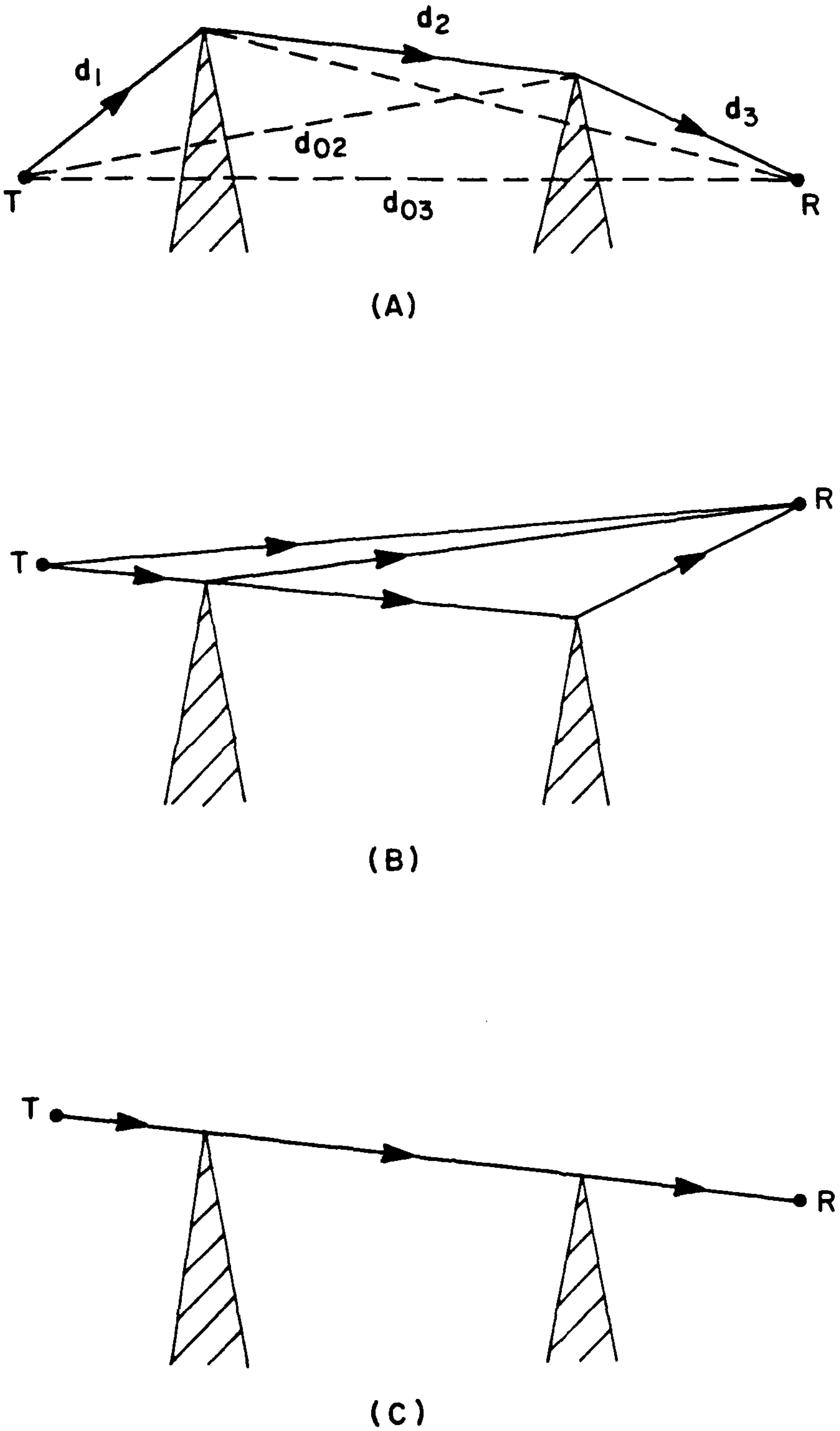

Figure 2-9 Double Edge Diffraction Path

If we substitute (2.55) into (2.54), we can express the reference path loss L_r in terms of the diffraction losses $f_1 = f(\nu_1, \rho_1)$ and $f_2 = f(\nu_2, \rho_2)$ as

$$\frac{1}{L_r} = \frac{P_R}{P_T G_T G_R} = A_b \left(\frac{\lambda}{4\pi d_1}\right)^2 \left(\frac{d_1(d_2+d_3)}{d_2(d_1+d_2+d_3)} f_1^2\right)\left(\frac{d_2}{d_2+d_3} f_2^2\right)\left(\frac{d_1}{d_1+d_2+d_3}\right)$$

$$= A_b \left(\frac{\lambda}{4\pi d}\right)^2 f_1^2 f_2^2 \qquad (2.58)$$

where $d = d_1 + d_2 + d_3$. The factor $(\lambda/4\pi d)^2$ in (2.57) is the free-space loss, while f_1^2 and f_2^2 are the diffraction losses due to each obstacle. The above expression is in agreement with the Fresnel-Kirchoff theory for double knife-edge diffraction [Millington, et al., 1962] when at least one of the diffraction angles is large. When both diffraction angles are small, the diffraction loss predicted by (2.57) is slighty pessimistic by less than 3 dB. The results presented here are valid for the case of diffraction by two rounded edges but can be generalized in a straightforward manner to an arbitrary number of edges. Since the Fresnel parameters ν_1 and ν_2 (arguments of f_1 and f_2) are defined as positive quantities (see Equation (2.55)), it should be pointed out that (2.54) and (2.57) apply only when the diffraction angles are positive (Figure 2-9a).

If one or more of the diffraction angles is negative (e.g., Figure 2-9b), the expression for the received signal consists of the sum of a number of rays some of which have undergone single scattering (from the first or second edge), double scattering

where

$$A(\nu,0) = -10 \log\{\frac{1}{2} [f^2(\nu) + g^2(\nu)]\}, \quad \nu > 0 \tag{2.56b}$$

$$f(\nu) = \frac{1 + .926\nu}{2 + 1.792\nu + 3.104\nu^2}$$

$$g(\nu) = \frac{1}{2 + 4.142\nu + 3.492\nu^2 + 6.67\nu^3}$$

$$A(0,\rho) = 6.02 + 7.192\ \rho - 2.018\ \rho^2 + 3.63\ \rho^3 - 0.754\ \rho^4 \text{ dB} \tag{2.56c}$$

$$U(\nu\rho) = \begin{cases} -\ 6.02 - 6.7\ \nu\rho + (43.6 + 23.5\ \nu\rho) \log(1+\nu\rho), & \nu\rho < 2 \\ -14.13 + 22\ \nu\rho - 20 \log \nu\rho\ , & \nu\rho > 2 \end{cases} \tag{2.56d}$$

The first term in (2.56a), i.e., $A(\nu,0)$ (coded AV in subroutine DIF1), is the diffraction loss due to an ideal knife-edge. The second term, $A(0,\rho)$ (coded ARHO in DIF1) is the diffraction loss due to a rounded edge at grazing incidence. The last term, $U(\nu\rho)$ (coded UVR in DIF1), accounts for the additional losses due to propagation along the surface of the rounded edge. The polynomial approximations for the diffraction loss due to a rounded edge are similar but differ from those used in NBS Tech Note 101 [P.L. Rice, et al., 1967] in that they incorporate newer more accurate approximations obtained by Dougherty and Wilkerson [1967].

$$D_2(\Theta_2) = \sqrt{\frac{kd_2d_3}{d_2+d_3}} \quad f(\nu_2, \rho_2) \tag{2.55b}$$

with

$$\nu_1 = |\Theta_1| \sqrt{\frac{2d_1(d_2+d_3)}{\lambda(d_1+d_2+d_3)}} \tag{2.55c}$$

$$\nu_2 = |\Theta_2| \sqrt{\frac{\lambda d_2 d_3}{\lambda(d_2+d_3)}} \tag{2.55d}$$

$$\rho_1 = (\frac{\lambda}{\pi} \; \frac{d_1+d_2+d_3}{d_1(d_2+d_3)})^{1/2} \; (\frac{\pi R_1}{\lambda})^{1/3} \tag{2.55e}$$

$$\rho_2 = (\frac{\lambda}{\pi} \; \frac{d_2 + d_3}{d_2 d_3})^{1/2} \; (\frac{\pi R_2}{\lambda})^{1/3} \tag{2.55f}$$

and $f(\nu, \rho)$ is the well known diffraction loss (loss above free-space loss) due to a single isolated rounded edge [Dougherty and Maloney, 1964], that is

$$A(\nu,\rho) = -20 \log|f(\nu,\rho)| = A(\nu,0) + A(0,\rho) + U(\nu\rho) \tag{2.56a}$$

where P_T is the transmitted power, $G_T(\Theta_T) = G_T|g_T(\Theta_T)|^2$ and $G_R(\Theta_T) = G_R|g_R(\Theta_R)|^2$ are the transmit and receive antenna gains at the transmit and receive horizon elevation angles, Θ_T (i.e., THET) and Θ_R (i.e., THER) respectively, $1/A_b$ is the atmospheric absorption loss defined earlier, d_1 is the great circle distance between the transmitter and the first obstacle, d_2 is the distance between obtacles, d_3 is the distance between the second obstacle and the receiver, $k = 2\pi f/c$, $D_1(\Theta_1)$ and $D_2(\Theta_2)$ are edge diffraction coefficients to be defined and which depend on the diffraction angles at the first obstacle, Θ_1, and at the second obstacle, Θ_2, respectively. The factor proportional to d_1^{-2} accounts for the spherical spreading loss between the transmitter and the first obstacle. The factor proportional to D_1^2 accounts for the diffraction loss at the first obstacle and the factor d_2^{-1} accounts for the cylindrical spreading loss (elevation plane) from the first to the second obstacle. Similarly, the factor proportional to D_2^2 accounts for the diffraction loss due to the second obstacle and the factor d_3^{-1} accounts for the cylindrical spreading between the second obstacle and the receiver. The last term d_1/d where $d = d_1 + d_2 + d_3$ is a factor which accounts for the azimuthal spreading from the first obstacle to the receiver. The extension of (2.54) to an arbitrary number of obstacles should be obvious from the above description.

The diffraction coefficients D_1 and D_2 are dimensionless quantities which depend on the diffraction angles, Θ_1 and Θ_2, and the radii of curvature of the obstacles, R_1 and R_2, if modeled as rounded edges. They are given by

$$D_1(\Theta_1) = \sqrt{\frac{kd_1(d_2+d_3)}{d_1+d_2+d_3}}\, f(\nu_1,\rho_1) \tag{2.55a}$$

specify either the minimum monthly refractivity at sea level (SEAN) or the effective earth radius ERFAC corresponding to this value. The two parameters SEAN and ERFAC, are not independent as shown in Section 2.5.2. A world map of the minimum monthly sea level refractivity, SEAN, is shown in Figure 2-3. On the other hand, maps of the minimum monthly effective earth radius factor are not available. The user may however have knowledge of the yearly median value of the effective earth radius factor for the desired climate. Therefore TROPO assumes that either the minimum monthly value of the surface refractivity, SEAN, or the yearly median value of the effective earth radius factor, ERFAC, is supplied by the user. If both are specified, ERFAC is ignored and a new value is computed from SEAN according to the relationships given in Section 2.5.2. Whenever SEAN is used to calculate the reference diffraction loss, climate dependent correction factors are required to estimate the yearly median path loss. The user may choose to use the yearly median value of the effective earth radius factor ERFAC for the climate of interest as a reference by specifying this value and specifying SEAN = 0. However, when the median value ERFAC is used as the basis for the reference path loss calculation no median correction factors are necessary because a great deal of the yearly variability in the diffraction loss is due to variability in the effective earth radius factor. This is clearly evident from the diffraction path loss curves for a double edge diffraction path shown in Figure 2-4 as a function of the effective earth radius factor.

The reference path loss $L_r = P_T G_T G_R / P_R$ is calculated in subroutine MDIF. When the path is a double diffraction path the received signal level P_R is calculated from

$$P_R = P_T G_T(\Theta_T) G_R(\Theta_R) A_b \left(\frac{\lambda}{4\pi d_1}\right)^2 \frac{|D_1(\Theta_1)|^2}{kd_2} \frac{|D_2(\Theta_1)|^2}{kd_3} \left(\frac{d_1}{d_1+d_2+d_3}\right) \tag{2.54}$$

$$q = \Pr\{v < V\} = \Pr\{v_1 + v_2 + v_3 < V\} \qquad (2.53b)$$

where v is a random variable whose distribution is q(V) and the inverse of the distribution V(q) is called the variability. Similarly v_1, v_2 and v_3 are random variables whose distributions are the inverse of the variabilities defined above for each section of the path. Thus it can be seen from (2.53b) that the distribution q(V) is found by convolving the distributions (actually by convolving the probability densities) $q(V_1)$, $q(V_2)$ and $q(V_3)$. The convolution of the densities is performed in subroutine CONVOL.

Prediction errors are accounted for in the same way as for the troposcatter signal by defining the diffraction RSL not exceeding q% of the year with (service) probability t as

$$P(q,t) = P(q,0.5) - T\sqrt{12.73 + .12\ Y_0^2(q)}$$

where P(q,0.5) is given by (2.52) and T is related to the service probability t by Eq. (2.3b).

2.6.2 The Reference Diffraction Path Loss

As in the troposcatter propagation mode, the path loss L_r for diffraction paths is the loss in continental temperate climates during weak signal periods (winter afternoons). The diffraction signal is weakest when the sea level refractivity N_0 or the effective earth radius factor ERFAC reaches a minimum value. This can be seen from the diffraction loss curves as a function of the effective earth radius shown in Figure 2-4. Therefore in order to determine the reference path loss the user must ideally

$$V(q) = V(50) + Y_0(q) \quad \text{dB} \tag{2.53a}$$

where V(50) is the median correction factor which, as in the troposcatter case, is climate zone and path length dependent, and $Y_0(q)$ is the variability about the median.

The variability of the diffraction signal is calculated by considering the diffraction path as a succession of line-of-sight paths, each of which exhibits independent long-term variations since the variations are terrain dependent and the terrain differs for each section of the path. The variability of each section of the diffraction path is calculated in the same manner as for the troposcatter path. Thus if the ray path is a double edge diffraction path as in Figure 2-7, the variability for each section of the path is given by

$$V_1(q) = V_1(50) + Y_1(q) \quad \text{dB}$$

$$V_2(q) = V_2(50) + Y_2(q) \quad \text{dB}$$

$$V_3(q) = V_3(50) + Y_3(q) \quad \text{dB}$$

where $V_1(50)$, $V_2(50)$ and $V_3(50)$ are median correction factors for each section of the path and $Y_1(q)$, $Y_2(q)$ and $Y_3(q)$ are the variability about the median. All of these parameters depend on the climate zone and an effective distance parameter, d_e, which depends on the terrain below the path and hence differs for each section of the path. The parameter d_e was defined earlier in Section 2.5.4.6.

The variability V(q) for the entire path is found by noting that the fraction of the year q for which the variability does not exceed V dB is by definition

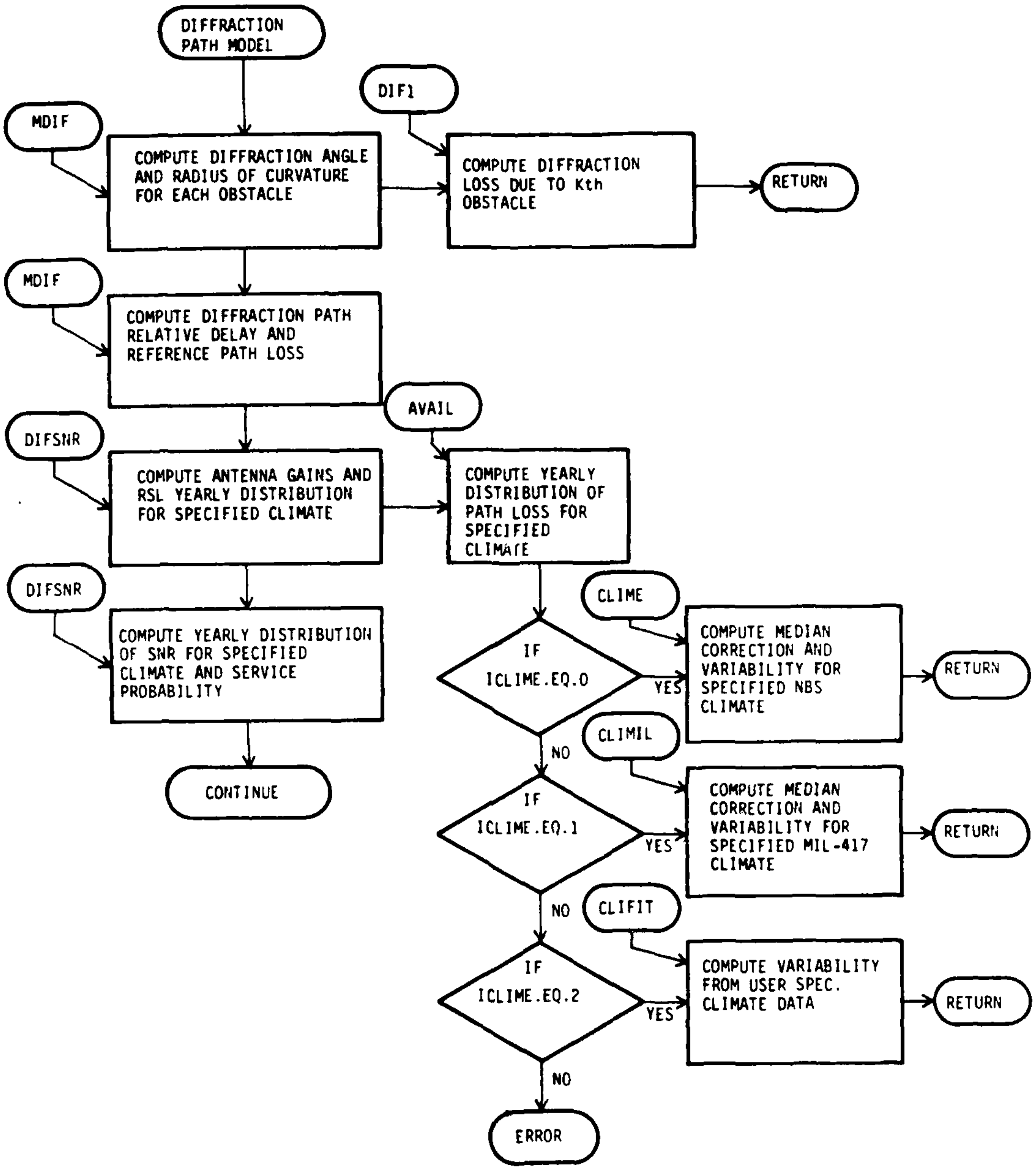

Figure 2-8 Flow Chart for Diffraction Propagation Parameter Calculations

In order to determine the variability of the path loss about the reference value, the following additional terrain information is needed: average terrain elevation above sea level at the transmit and receive sites, AVETX and AVERX respectively, and the average terrain elevation above sea level at each obstacle site, HLAV(1), ..., HLAV(NOBS) respectively. These values need only be approximate and may be estimated from topographical data such as that obtained from Figure 2-7. However if accuracy is desired, the program can calculate the average terrain elevation at each obstacle site as well as at the transmit and receive sites from evenly-spaced terrain data between each obstacle, and between the first and last obstacle and the two terminals. The details of the calculation have been discussed earlier in Section 2.5.4. More details about the format of the terrain data to be supplied are given in the User's Manual Report. The program structure of the diffraction calculations is shown in Figure 2-8.

2.6.1 RSL and Path Loss Distributions

Although the diffraction signal is not a fading signal, it exhibits long-term (yearly) variations.

The RSL exceeded q% of the year, P(q), which corresponds to the diffraction path loss not exceeded that same q% of the time, L(q), is defined as

$$\begin{aligned} P(q) &= P_r + V(q) \quad \text{dBW} \\ L(q) &= L_r - V(q) \quad \text{dB} \end{aligned} \tag{2.52}$$

where P_r and L_r are the reference RSL and reference path loss respectively, and V(q) is the variability of the diffraction signal about the reference. The variability V(q) can also be expressed as

$$R_c = DS/\Theta_d \tag{2.51}$$

where Θ_d (coded ANG(.) in MDIF) is the angle of diffraction which is calculated in the program from the terrain data provided by the user. The diffraction loss can vary by as much as 15 dB/obstacle when the horizontal extent of the obstacle is varied from 0 (knife-edge) to 0.4 miles as seen from the curves of Figure 2-4 (double edge diffraction path) which indicates the importance of providing an accurate estimate of this parameter. Plotted path profiles such as that of Figure 2-7 are not detailed enough to allow us to get a good estimate of DS for each obstacle. Detailed topographic maps are needed to do so. However they may not always be available. If that is the case, a reasonable value for DS should be provided anyway keeping in mind that at microwave frequencies, most obstacles do not behave as knife-edges, and that horizontal extents greater than .4 miles may result in an overestimate of the path loss especially when the obstacles appear to be knife-edges on maps such as that of Figure 2-7.

The above terrain data as well as the great circle path distance D, transmit and receive site elevation above sea level, HTO and HRO respectively, transmitting and receiving antenna nominal heights, HT and HR respectively, and either the refractivity at sea level, SEAN, or an effective earth radius factor, ERFAC, provide sufficient information to calculate a reference path loss. The terrain between the obstacles is assumed to be rough so that ground reflections are not included in the calculation. It must not, however, have any prominent peaks which either obstruct or just touch the ray path. If that is the case, they should be treated as additional obstacles. Terrain features which do not obstruct the path should not be entered as obstacles as their effect on the path loss is considered statistically in the calculation of the long term variability of the diffraction path loss.

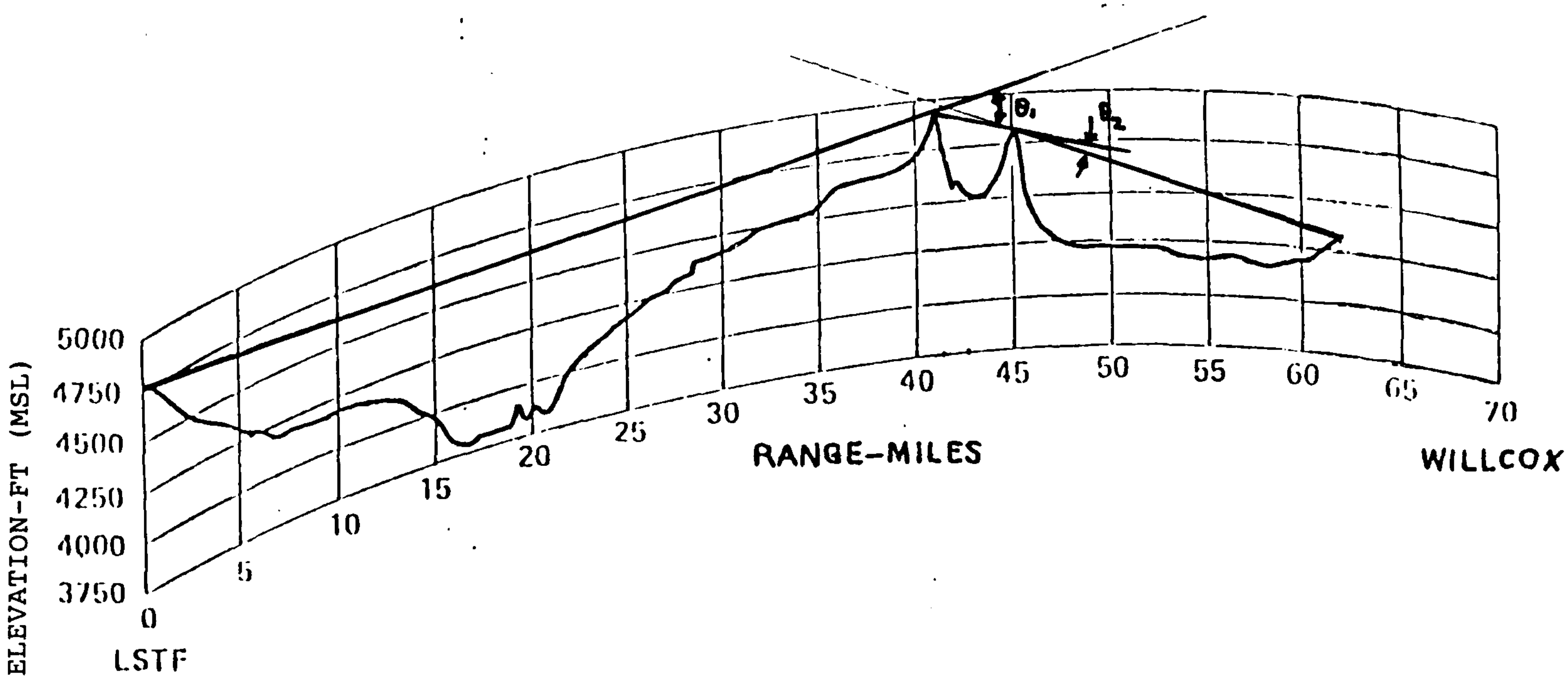

Figure 2-7 Path Profile: LSTF to WILLCOX

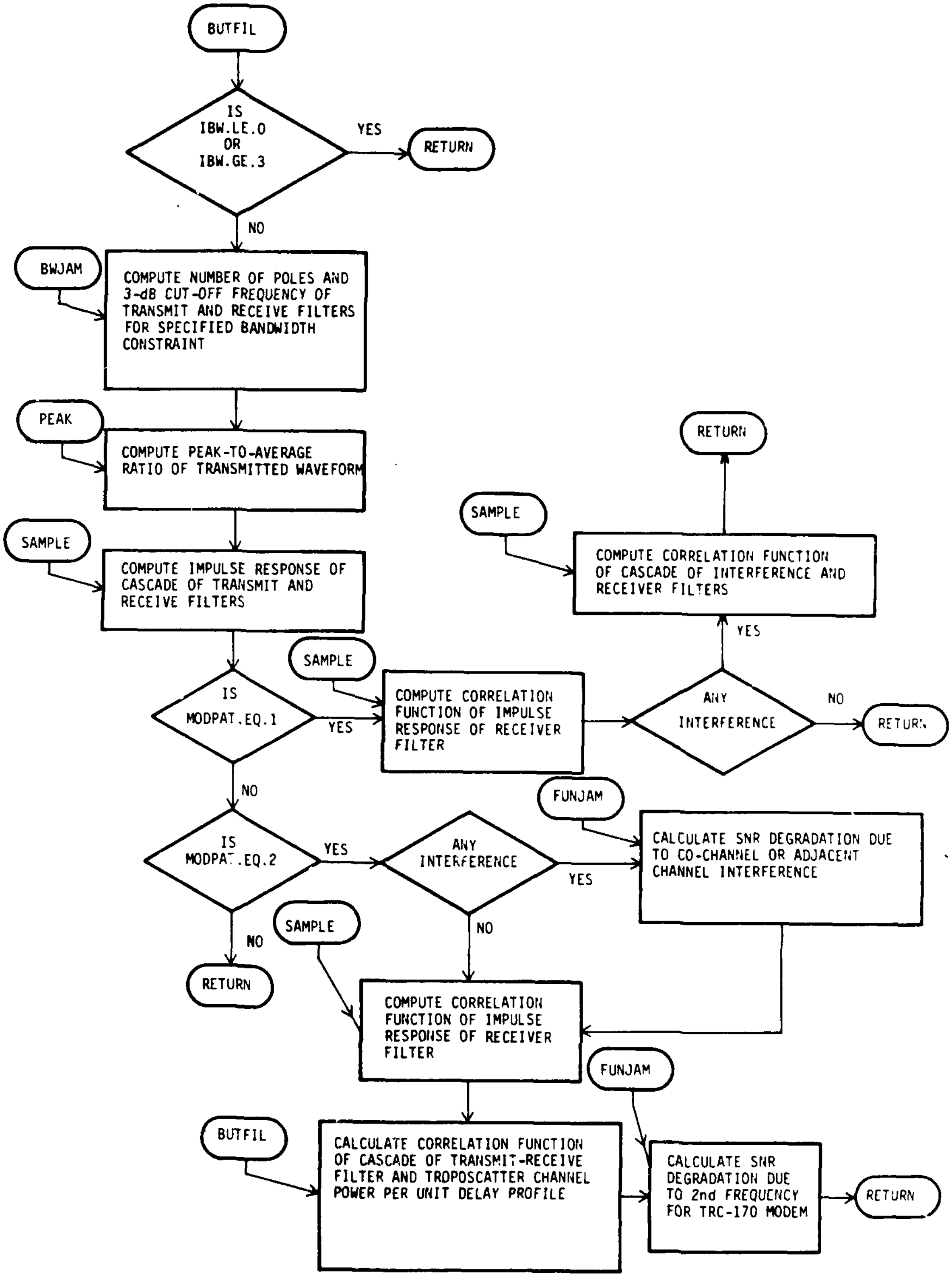

Figure 2-10 Flow Chart for Filter and Interference Effects Calculations

$$S(f) = \left|B_N(f/f_c)\right|^2 \operatorname{sinc}^2 Tf \qquad (2.59)$$

where $B_N(f/f_c)$ is the baseband transfer-function of the N-pole Butterworth filter with 3 dB cut-off frequency f_c (half of 3-dB bandwidth), i.e.,

$$B_N(f/f_c) = \frac{1}{1 + j(f/f_c)^N} \qquad (2.60)$$

and

$$\operatorname{sinc}(Tf) = \frac{\sin(\pi Tf)}{\pi Tf} \quad . \qquad (2.61)$$

The number of poles and the 3 dB cut-off frequency can be specified by the user (IBW = 3) or be calculated by the program to achieve the necessary filtering so that either 99% of the power is within the specified bandwidth (IBW = 1), or to meet the FCC-19311 mask for the specified bandwidth (IBW = 2). If IBW = 0 is specified, the program assumes that there is no RF filtering in the transmitter. The baseband pulse duration T is defined as

$$T = \begin{cases} 2/R_c & \text{for MD-918 Modem} \\ 1/R_c & \text{for AN/TRC-170 and DAR Modems} \end{cases} \qquad (2.62)$$

where R_c is equal to the data rate for the AN/TRC-170 and DAR modems. For the MD-918 modem,

$$R_c = K_c R, \; K_c > 1$$

where R is the data rate and K_c is the integer part of the ratio of the bandwidth, B, to the data rate, R. That is, K_c is the

number of chips per data bit. TROPO assumes that when the data rate specified by the user is less than half the specified bandwidth, the MD-918 uses a PN sequence to expand the bandwidth and exploit the implicit diversity of the troposcatter channel. The present version of TROPO calculates the performance of the AN/TRC-170 for bandwidths not greater than 4 times the data rate.

The impulse response of the transmitted waveform is given by

$$h_T(t) = \int_{-\infty}^{\infty} B_N(f/f_c)\text{sinc } Tf \; e^{-j2\pi ft} df \tag{2.63}$$

and the peak-to-average ratio is defined as

$$\text{PEAKAV} = \max_{0<t<T} \frac{|h(t)|^2}{\int_{-\infty}^{\infty} |h(t')|^2 dt'} \;. \tag{2.64}$$

2.7.1 Receiver Filtering

The receiver filters for the MD-918 consist of the cascade of a Butterworth filter and a filter matched to the baseband pulse shape of the transmitted waveform (rectangular impulse response of duration T). The number of poles and the 3-dB cut-off frequency, f_c, of the receiver Butterworth filter are specified by the user when IBW = 3. Otherwise (IBW = 1 or 2) the Butterworth filter is a 4 pole filter with 3-dB cut-off frequency given by

$$f_c = 0.5B \tag{2.65}$$

where B is the bandwidth specified by the user.

The receiver filtering for the DAR modem consists of a 4-pole Butterworth filter and 3-dB cut-off frequency $f_c = B$ while the receiver filtering for the AN/TRC-170 modem consists of a 6-pole Butterworth filter with 3-dB cut-off frequency equal to that of the transmitter filter.

When adjacent channel interference calculations are desired the number of poles and 3-dB cut-off frequency of the receiver Butterworth filter for the MD-918, DAR and AN/TRC-170 modems are calculated so that the SNR degradation of the adjacent channel interference is less than 1 dB.

The impulse response of the cascade of the transmitter and receiver filters is defined as

$$f(t) = \int_{-\infty}^{\infty} H_T(f)\, H_R(f) e^{-j2\pi ft} df \tag{2.66}$$

where $H_T(f)$ and $H_R(f)$ are the baseband transfer functions (Fourier transform of impulse response) of the transmitter and receiver filters.

The correlation function of the receiver filter is defined as

$$f_R(t) = \int_{-\infty}^{\infty} \left|H_R(f)\right|^2 e^{-j2\pi ft} df \tag{2.67}$$

2.7.2 Interference Correlation Calculations

The correlation function of the cascade of the interfering signal and the receiver filters is defined as

$$g(t) = \int_{-\infty}^{\infty} |H_R(f)|^2 \; [P_I(f-f_s) + P_I(f+f_s)]e^{-j2\pi ft}df \qquad (2.68)$$

where $H_R(f)$ is the baseband transfer function of the receiver filter, $P_I(f)$ is the baseband power spectrum of the interfering signal, and f_s is the frequency separation between the center frequencies (carrier) of the transmitted signal and the interfering signal.

When the interfering signal is an FDM/FM signal (MODSIG=0), the baseband power spectrum of the interferring signal is assumed to be of the form

$$P_I(f) = \frac{1}{\sqrt{\pi}\; f_0} e^{-f^2/f_0^2} \qquad (2.69)$$

with

$$f_0 = \frac{B_I}{2.577\sqrt{2}} \qquad (2.70)$$

and where B_I is the 99% bandwidth of the interfering signal.

When the interfering signal is a QPSK signal (MODSIG=1), the baseband power spectrum of the interfering signal is assumed to be of the form

$$P_I(f) = \frac{1}{1 + (f/f_c)^{2N}} \operatorname{sinc}^2(2f/B_I) \qquad (2.71)$$

where the number of poles N=2 and the 3-dB cut-off frequency f_c are calculated so that 99% of the interference power is within the bandwidth B_I.

2.8 MD-918 MODEM PERFORMANCE

When the MD-918 modem is selected (MODPAT = 1 in the input file), TROPO calculates the short-term average bit error rate, 1000 bit block error rate, fade outage probability and fade outage per call minute* (coded BERAV, SUM2, PFO and FCMIN in subroutine BERCAL), given the troposcatter power per unit delay profiles and the correlation between diversity branches, as a function of the average (short-term) signal-to-noise ratio $\overline{E}_b/N_0$ (i.e., energy per bit/noise spectral noise). A numerical integration over the long term variability in average signal-to-noise ratio then gives the yearly average fade outage probability and the yearly average fade outage per call minute, assuming log-normal long-term fading statistics for the troposcatter signal and the diffraction signal (if mixed mode propagation is indicated).

The MD-918 employs an adaptive Decision Feedback Equalizer (DFE) to process the received signal. The DFE consists of an Adaptive Forward Equalizer (AFE) filter for each diversity input and an Adaptive Backward Equalizer (ABE) filter, both of which are tapped delay lines. A block diagram of the MD-918 is shown in Figure 2-11. The ABE filter has 3 taps with spacing equal to a QPSK symbol duration (twice the inverse of the data rate) while

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* NOTE: The fade outage probability and fade outage per call minute are defined later in this section.

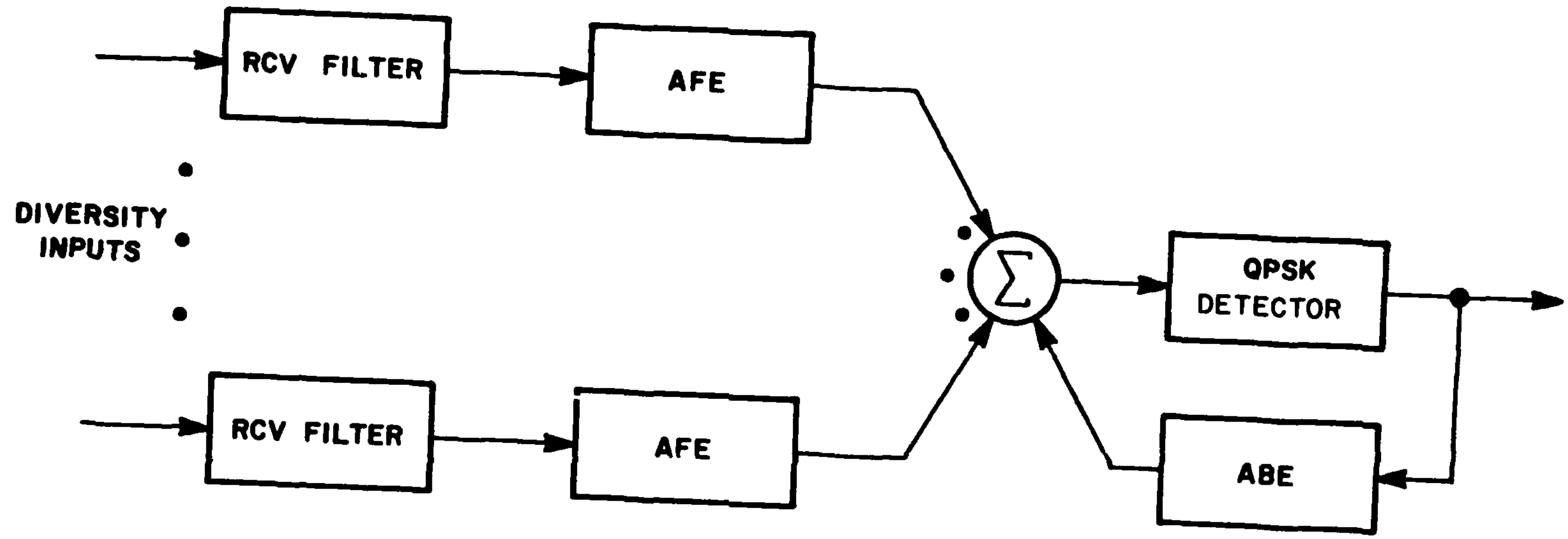
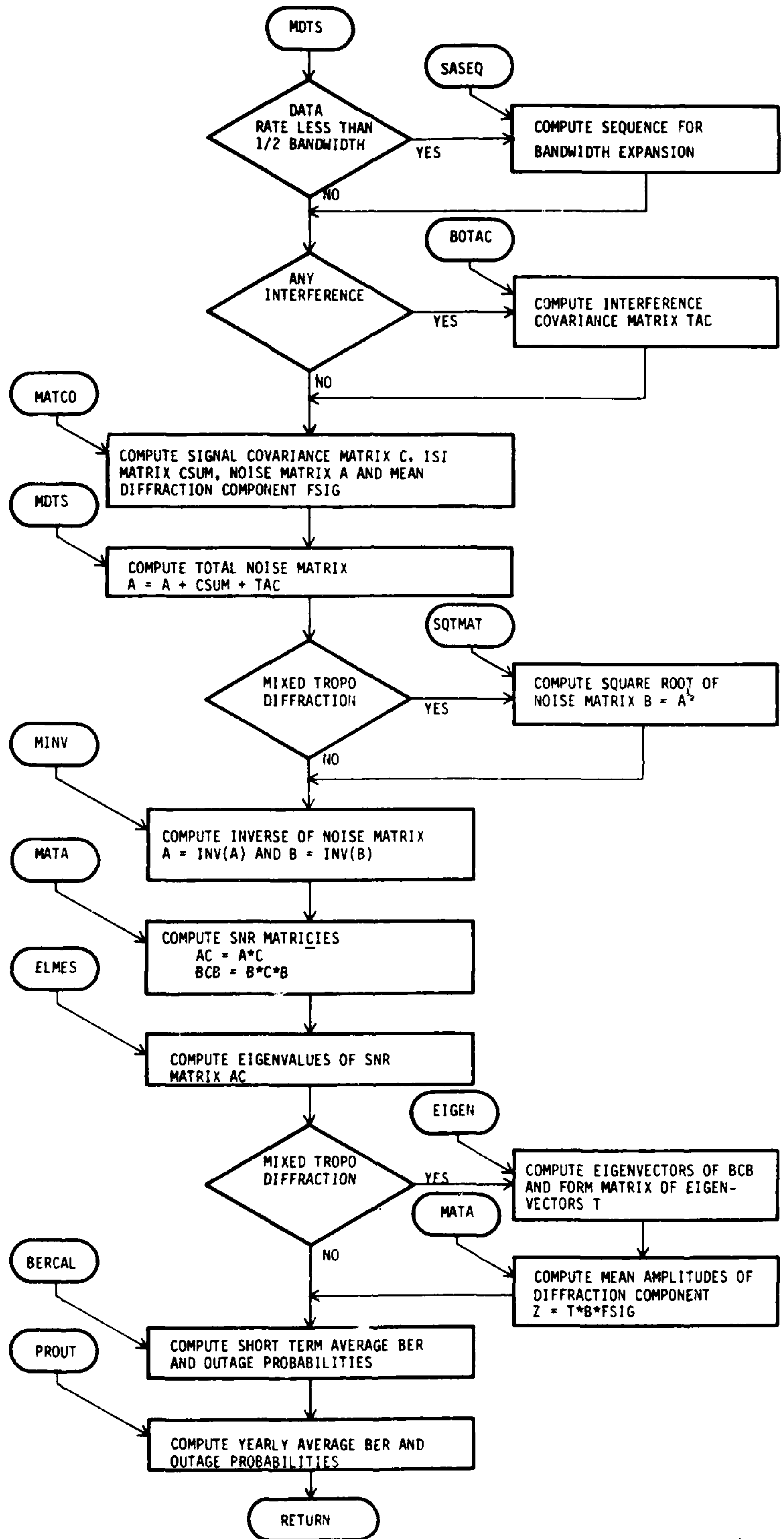


Figure 2-11 MD-918 Receiver Structure

each of the AFE filters has 3 taps with spacing equal to 1/2 of the QPSK symbol duration. The ABE filter removes the intersymbol interference (ISI) due to the past 3 symbols. The TROPO program assumes that the ISI due all the other past symbols is negligible when the received signal consists of a pure troposcatter signal. When mixed troposcatter/diffraction paths are specified, the TROPO program accounts in the calculations for the ISI due to the fourth and fifth past symbols, which are not cancelled by the backward equalizer, in addition to the ISI due to a specified number (LISI) of future symbols. The AFE filters combine the explicit diversity branches, remove ISI due to future symbols and provide some implicit diversity gain when the tap outputs are uncorrelated. The modem performance depends on the number of (explicit) diversity branches (space, frequency, angle, etc.), number of AFE filter taps (fixed equal to 3) the tap spacing and the ratio of the data rate to the bandwidth. Although the tap-spacing is fixed in the MD-918, the user has the option of specifying the normalized tap spacing (default = 0.5) as well as the number of future symbols which are to be included in the ISI calculation (default = 2) and the diversity configuration (see Section 2.5.6). The data rates DRATE (in bits per second) for which modem performance calculations are allowed must satisfy

$$\frac{BW}{30} < \text{DRATE} < 2BW$$

where BW is the bandwidth in Hz. In the remainder of this section we present an overview of the analytical models used to calculate the various performance measures. The main routine for the calculation of the MD-918 performance is subroutine MDTS. A block diagram of the main calculations performed is shown in Figure 2-12.



'igure 2-12 Flow Chart for the MD-918 Modem Performance Calculations

2.8.1 Short-Term Performance

2.8.1.1 Short-Term Average Bit Error Rate, Troposcatter Propagation

When the received signal is a pure troposcatter signal, the short-term average bit error rate is calculated by averaging the instantaneous bit error rate over the Rayleigh statistics of the troposcatter signal.

At a particular instant of time, the instantaneous bit error rate of the MD-918 modem is well approximated by* [Monsen, 1977]

$$P_e = \frac{1}{2} e^{-\rho} \qquad (2.72)$$

where ρ is the effective instantaneous signal-to-noise ratio after equalization.

The effective signal-to-noise ratio is a random variable given by the sum [Equations 19 and 33, Monsen, 1977]

$$\rho = \frac{\overline{E_b}}{N_0} \sum_{i=1}^{N} |\alpha_i|^2 \qquad (2.73)$$

where N = IxK, I is the number of implicit diversity channels (i.e., number of taps in the adaptive-forward-equalizer) and K is the number of explicit diversity channels (i.e., space, frequency or angle diversity channels), $\overline{E_b}/N_0$ is the average signal-to-

* The DPSK error rate characteristic is a good approximation to the MD-918 BER performance at low error rates.

noise ratio per bit per explicit diversity branch and the α_i are independent zero-mean complex Gaussian random variables with variance

$$\overline{|\alpha_i|^2} = \lambda_i \quad , \quad i = 1, \ldots, N \tag{2.74}$$

where the λ_i are eigenvalues of the non-symmetric SNR matrix $A^{-1}C$. The matrix C is the received signal covariance matrix whose diagonal elements represent the average signal power per diversity (implicit and/or explicit) branch and the off-diagonal elements are proportional to the correlation between the implicit (taps) and explicit diversity branches [Monsen, 1977]. The covariance matrix C is normalized so that the total power per explicit diversity is unity. The matrix A is the total noise covariance matrix and is equal to the sum

$$A = A_T + \frac{\overline{E_b}}{N_0} A_{ISI} + \frac{N_J}{N_0} A_I \tag{2.75}$$

where A_T is the receiver thermal noise covariance matrix normalized to unity noise power density (its elements are a function of the impulse response of the receiver filters), A_{ISI} is the nonsymmetrical covariance matrix of the future intersymbol interference*, N_J is the effective interference power density (cochannel or adjacent channel) in the bandwidth of interest, N_0 is the thermal noise power density and A_I is the covariance matrix

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* The past ISI is assumed to be cancelled by the backward equalizer in the MD-918.

of the interference signal whose diagonal elements represent the interference signal power (in the bandwidth of interest) per diversity branch relative to the thermal noise power and the off-diagonal elements are proportional to the correlation between the interference on the various diversity branches.

The short-term average bit error rate is then found by performing the averaging over the statistics of ρ, i.e.,

$$\overline{P_e} = \frac{1}{2} \int_0^\infty e^{-x} f(x/\overline{E}_b/N_0)\, dx = \frac{1}{2} F(1/\overline{E}_b/N_0) \tag{2.76}$$

where $f(x/\overline{E}_b/N_0)$ is the probability density function of the effective SNR, ρ, conditional on a fixed value of the average SNR per bit, $\overline{E}_b/N_0$ and $F(s/\overline{E}_b/N_0)$ is its Laplace transform, i.e.,

$$F(s/\overline{E}_b/N_0) = \int_0^\infty f(x/\overline{E}_b/N_0) e^{-sx}\, dx \quad .$$

The Laplace transform of the conditional pdf for ρ can be found analytically by noting that the random variable α_i is Rayleigh distributed and hence $|\alpha_i|^2$ has an exponential pdf whose Laplace transform is

$$F_i(s) = (1 + \lambda_i s)^{-1} \quad .$$

Since the $|\alpha_i|^2$ are independent, the Laplace transform of the conditional pdf for ρ is

$$F(s/\overline{E}_b/N_0) = \sum_{i=1}^{N} \left(1 + \frac{\overline{E_b}}{N_0} \lambda_i s\right)^{-1} \quad . \tag{2.77}$$

The short-term average bit error rate can then be found from (2.76) and (2.77) for a given value of $\overline{E}_b/N_0$ provided the eigenvalues λ_i can be found.

The eigenvalues λ_i are evaluated in the TROPO program (subroutine MDTS) by making certain simplifying assumptions in order to reduce the computational load. In general, one must find N = IxK eigenvalues of the NxN SNR matrix $A^{-1}C$. For large explicit diversity (e.g., for 2S/2F/2A K = 8) and a three-tap forward equalizer (I=3) a rather large matrix results (24x24 in this example). To avoid unnecessary computations, use is made of the fact that the matrix has a redundant block structure whenever two or more of the explicit diversity branches are uncorrelated. Furthermore if two or more uncorrelated explicit diversity branches have equal average received power and equal delay spreads, they will have identical implicit diversity eigenvalues $\lambda_i \overline{E}_b/N_0$. The block structure of the SNR matrix $A^{-1}C$ will vary from one diversity configuration to another and hence so will the eigenvalues.

When only one antenna is used to transmit and two spaced antennas are used to receive (DIVTYP=0) there are four possible diversity configurations depending on whether frequency and/or angle diversity are used in conjunction with space diversity. The possible diversity configurations are: dual space (2S), dual space/dual frequency (2S/2F), dual space/dual angle (2S/2A), and dual space/dual angle/dual frequency diversity (2S/2A/2F). If the antennas are spaced far enough apart and the frequency diver-

separation is greater than the sum of the bandwidth and the rence bandwidth of the troposcatter channel, then the space rsity and frequency diversity channels are uncorrelated. The e diversity channels are correlated, however, because the two ive antenna beams overlap. Thermal noise is uncorrelated on explicit diversities. Thus, in the absence of any interfer- signal (co-channel or adjacent), the SNR matrix for these diversity configurations have the following block structure:

2S:

$$A^{-1}C = \begin{bmatrix} C_{11} & 0 \\ 0 & C_{22} \end{bmatrix}$$

2S/2F:

$$A^{-1}C = \begin{bmatrix} C_{11} & 0 & 0 & 0 \\ 0 & C_{12} & 0 & 0 \\ 0 & 0 & C_{21} & 0 \\ 0 & 0 & 0 & C_{22} \end{bmatrix}$$

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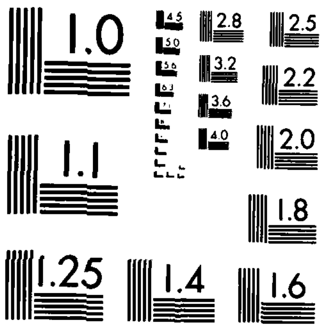

MICROCOPY RESOLUTION TEST CHART
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For 2S/2A:

$$A^{-1}C = \begin{bmatrix} C_{11}(A_{11}) & C_{11}(A_{12}) & 0 & 0 \\ C_{11}(A_{12}) & C_{11}(A_{22}) & 0 & 0 \\ 0 & 0 & C_{22}(A_{11}) & C_{22}(A_{12}) \\ 0 & 0 & C_{22}(A_{12}) & C_{22}(A_{22}) \end{bmatrix}$$

For 2S/2A/2F:

$$A^{-1}C = \begin{bmatrix} C_{11}(A_{11}) & C_{11}(A_{12}) & 0 & 0 & 0 & 0 & 0 & 0 \\ C_{11}(A_{12}) & C_{11}(A_{22}) & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & C_{12}(A_{11}) & C_{12}(A_{12}) & 0 & 0 & 0 & 0 \\ 0 & 0 & C_{12}(A_{12}) & C_{12}(A_{22}) & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & C_{21}(A_{11}) & C_{21}(A_{12}) & 0 & 0 \\ 0 & 0 & 0 & 0 & C_{21}(A_{12}) & C_{21}(A_{22}) & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & C_{22}(A_{11}) & C_{22}(A_{12}) \\ 0 & 0 & 0 & 0 & 0 & 0 & C_{22}(A_{12}) & C_{22}(A_{22}) \end{bmatrix}$$

where $C_{ij}(A_{11})$ and $C_{ij}(A_{22})$ are 3x3 SNR covariance matrices for the three equalizer taps corresponding to the lower beam (A_{11}) and upper beam (A_{22}) of the i'th space diversity receiving antenna at the j'th frequency diversity. $C_{ij}(A_{12})$ is a 3x3 matrix whose elements are proportional to the cross-correlation between

the signals on the three taps in the upper and lower beams of the ith space diversity antenna at the jth frequency diversity.

Since the average signal-to-noise ratio, E_b/N_0, is identical for the two space diversities and/or the two frequency diversities, the redundant block structures of the SNR matrix $A^{-1}C$ show that 2S and 2S/2F have 3 distinct eigenvalues (one for each tap) while 2S/2A and 2S/2A/2F have 6 distinct eigenvalues (3 for the lower beam taps and 3 for the upper beam taps).

The block structures shown above apply only in the absence of any interfering signal. When a co-channel or adjacent channel interferer is present, the interference on the two spaced antennas is correlated so that in general the SNR matrix will not have the simple structure indicated above. Because of the complexity involved in analyzing all possible diversity configurations in the presence of interference, we have concentrated on modeling the effects of the interference on 2S/2F diversity configurations only. The SNR matrix structure for this diversity configuration is in this case

$$A^{-1}C = \begin{bmatrix} C_1(S_{11}) & C_1(S_{12}) & 0 & 0 \\ C_1(S_{12}) & C_1(S_{22}) & 0 & 0 \\ 0 & 0 & C_2(S_{11}) & C_2(S_{12}) \\ 0 & 0 & C_2(S_{12}) & C_2(S_{22}) \end{bmatrix}$$

where $C_j(S_{11})$ and $C_j(S_{22})$ are 3x3 SNR covariance matrices for the three taps corresponding to the space diversity antennas 1 and 2, respectively, at the jth frequency. $C_j(S_{12})$ is a 3x3 matrix whose elements are proportional to the cross correlation between the taps for Antenna 1 and the taps for Antenna 2. The interference is assumed to be uncorrelated at the two frequency diversities. The number of distinct eigenvalues for the 2S/2F diversity configuration in the presence of an interfering signal is 6.

When only one antenna is used to transmit and receive (DIVTYP=1), there are three possible diversity configurations: dual angle (2A), dual frequency (2F) and dual frequency/dual angle diversity (2F/2A). The SNR matrix structure for these three diversity configurations is (assuming no interference)

For 2A:

$$A^{-1}C = \begin{bmatrix} C_1(A_{11}) & C_1(A_{12}) \\ C_1(A_{12}) & C_1(A_{22}) \end{bmatrix}$$

For 2F:

$$A^{-1}C = \begin{bmatrix} C_1(A_{11}) & 0 \\ 0 & C_2(A_{11}) \end{bmatrix}$$

For 2F/2A:

$$A^{-1}C = \begin{bmatrix} C_1(A_{11}) & C_1(A_{12}) & 0 & 0 \\ C_1(A_{12}) & C_1(A_{22}) & 0 & 0 \\ 0 & 0 & C_2(A_{11}) & C_2(A_{12}) \\ 0 & 0 & C_2(A_{12}) & C_2(A_{22}) \end{bmatrix}$$

where $C_j(A_{11})$ and $C_j(A_{22})$ are 3x3 SNR matrices for the taps of the lower and upper beams, respectively, at the jth frequency diversity and $C_j(A_{12})$ is a 3x3 cross-correlation matrix for the taps of the lower and upper beams. These block structures indicate that there are 3 district eigenvalues for 2F and 6 distinct eigenvalues for 2A and 2F/2A.

Finally when two antennas are used to transmit the same information on orthogonal polarizations, and both polarizations are received on two spaced antennas (DIVTYP=2), there are two possible diversity configurations: dual space/dual polarization (2S/2P) and dual space/dual polarization/dual angle (2S/2P/2A). In the 2S/2P case there are four paths, two of which (paths 1 and 4 are called the parellel paths (see Figure 2-6), and two of which (paths 2 and 3) cross each other. Analysis of this diversity configuration has shown that only the crossing paths are correlated. The block structure of the SNR matrix for 2S/2P and 2S/2P/2A, assuming no interference, is:

For 2S/2P:

$$A^{-1}C = \begin{bmatrix} C_{11} & 0 & 0 & 0 \\ 0 & C_{22} & C_{23} & 0 \\ 0 & C_{23} & C_{33} & 0 \\ 0 & 0 & 0 & C_{44} \end{bmatrix}$$

For 2S/2P/2A:

$$A^{-1}C = \begin{bmatrix} C_{11}(A_1) & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & C_{22}(A_1) & C_{23}(A_1) & 0 & 0 & 0 & 0 & 0 \\ 0 & C_{23}(A_1) & C_{33}(A_1) & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & C_{44}(A_1) & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & C_{11}(A_2) & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & C_{22}(A_2) & C_{23}(A_2) & 0 \\ 0 & 0 & 0 & 0 & 0 & C_{23}(A_2) & C_{33}(A_2) & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & C_{44}(A_2) \end{bmatrix}$$

where the diagonal "elements" are 3x3 SNR matrices for the taps of each explicit diversity path and the off diagonal 'elements' are 3x3 cross correlation matrices for the taps of the crossing paths. The number of distinct eiginvalues for 2S/2P is 9 (paths 1 and 4 have identical eigenvalues) while 2S/2P/2A has 18 distinct eigenvalues.

2.8.1.2 Short Term Average Bit Error Rate, Mixed-Mode Propagation

When a specular component due to diffraction is introduced, the average bit error rate is calculated as follows. Let $\underline{q}_i$ be a vector whose elements represent samples of the signal component of the received signal. The signal vector $\underline{q}_i$ has the general form

$$\underline{q}_i = \{q(t_0 - iT - k\tau)\}_{k=-K_1}^{K_2} \tag{2.78}$$

where τ is the tap spacing on the AFE filter, T is the source symbol interval, t_0 is the sampling time and the subscript i denotes the ith transmitted symbol. The number of equalizer taps

is $K = K_1 + K_2 + 1$. The function $q(t)$ is defined in terms of the impulse responses of the transmit filter, $f_T(t)$, the receive filter $f_R(t)$, and the channel impulse response, $h(t)$. We have

$$q(t) = \bar{E}_b^{1/2} \int_{-\infty}^{\infty} f(t-t')h(t')dt', \quad f(t) = \int_{-\infty}^{\infty} f_T(t')f_R(t-t')dt' \tag{2.79}$$

If a_D and a_s are the fraction of received power in the diffraction and scatter components and Δ is the relative delay of the scatter component for mixed mode propagation, then

$$h(t) = \sqrt{a_D}\ \delta(t) + \sqrt{a_s}\ h_s(t-\Delta) \tag{2-80a}$$

and

$$q(t) = \sqrt{a_D}\ \bar{E}_b^{1/2} + \sqrt{a_s}\ \bar{E}_b^{1/2} \int_{-\infty}^{\infty} f(t-t')\ h_s(t'-\Delta)dt' \tag{2-80b}$$

which reduces to the scatter case when $a_D = 0$ and $\Delta = 0$.

To find the performance for mixed mode propagation one computes the matrices A and C as before but now they include the effects of the specular component through the fixed term in $q(t)$. Say we had computed the matrices for the scatter only case; call these A_s and C_s. In this calculation we choose a sampling time t_0 corresponding to the respective energies in the diffraction and scatter components.* If t_0 is the best sampling time when no scatter is present, a reasonable choice of sampling time would be

* NOTE: The selection of an appropriate sampling time reflects the operation of a symbol time tracker system under mixed mode conditions.

$$t_0 = t_{0D} - a_s \Delta \tag{2.81}$$

It is useful to define the scatter component of q(t) as

$$q_s(t) = \int_{-\infty}^{\infty} f(t-t')\ h_s(t'-\Delta)dt' \tag{2.82}$$

and the scatter signal vector

$$\underline{q}_{s_i} = \{q_s(t_0-iT-k\tau\}_{k=-K_1}^{K_2} \tag{2.83}$$

The matrices A_s and C_s are then

$$A_s = A_0 + \frac{\gamma^2 a_s \overline{E}_b}{N_0} \sum_{i \epsilon I_b} \overline{\underline{q}_{s_i} \underline{q}'_{s_i}} \tag{2.84}$$

$$C_s = \overline{\underline{q}_{s_0} \underline{q}'_{s_0}} \tag{2.85}$$

Because of the specular component, the combined noise matrix A is given by

$$A = A_s + \frac{\gamma^2 a_D \ \overline{E}_b}{N_0} \sum_{i \epsilon I_b} \underline{f}_i \ \underline{f}'_i \equiv A_s + A_D \tag{2.86}$$

where

$$\underline{f}_i = \{f(t_0 - iT - k\tau)\}_{k=-K_1}^{K_2} \tag{2.87}$$

and A_D is the ISI matrix due to diffraction.

The signal-to-noise ratio at the equalizer output is then

$$\rho = \frac{\overline{E}_b}{N_0} \left(\sqrt{a}_D \, \underline{f}_0 + \sqrt{a}_s \, \underline{q}_{s_0}\right)' A^{-1} \left(\sqrt{a}_D \, \underline{f}_0 + \sqrt{a}_s \, \underline{q}_{s_0}\right) \tag{2.88}$$

In order to determine the bit-error-rate statistics, one converts the above quadratic form into a quadratic form of uncorrelated variables. The transformation which accomplishes this is given by

$$\underline{z} = M'\underline{x} = T'B^{-1}\underline{x} \tag{2.89}$$

where

$$B = A^{1/2}$$

$$\underline{x} = \sqrt{a}_D \, \underline{f}_0 + \sqrt{a}_s \, \underline{q}_{s_0} \tag{2.90}$$

and M is the modal matrix for

$$CM = AM\Gamma \tag{2.91}$$

i.e.,

$$\Gamma = \{\Gamma_{ij}\} = \{\lambda_i \delta_{ij}\} \tag{2.92}$$

With this transformation, one obtains

$$\rho = \frac{\overline{E}_b}{N_0} \; \underline{z}'\underline{z} = \frac{\overline{E}_b}{N_0} \sum_{k=1}^{K} |z_k|^2 \tag{2.93}$$

The variates z_i are uncorrelated complex Gaussian with moments

$$\overline{\underline{z}} = \sqrt{a_D}\, M'\underline{f}_0 = \sqrt{a_D}\, T'B^{-1}\underline{f}_0 \tag{2.94}$$

$$\overline{|z_i - \overline{z}_i|^2} = a_s \lambda_i \tag{2.95}$$

The Laplace transform of the probability density function (pdf) for the signal-to-noise ρ in (2.88) is the product of Laplace transforms of each pdf for the component SNR ρ_i where

$$\rho_k = \frac{\overline{E}_b}{N_0} |z_k|^2 \tag{2.96}$$

The Laplace transform for each component is

$$\overline{e^{-s\rho_k}} = \frac{1}{2\pi\lambda_k} \int e^{-s\rho_k - |z_k - \overline{z}_k|^2/\lambda_k} \, dz_k \tag{2.97}$$

Completing the square and performing the indicated integration over the real and imaginary parts of z_k gives the result

$$\overline{e^{-s\rho_k}} = e^{-su_k/(1+sv_k)} (1+sv_k)^{-1} \tag{2.98a}$$

where

$$u_k = \overline{z}_k^2 \, \overline{E}_b/N_0 \tag{2.98b}$$

$$v_k = a_s \lambda_k \overline{E}_b/N_0 \tag{2.98c}$$

The Laplace transform for the SNR ρ is the product

$$\overline{e^{-s\rho}} = e^{-\sum_{k=1}^{K} su_k/(1+sv_k)} \prod_{\ell=1}^{K} (1+sv_\ell)^{-1} \tag{2.99}$$

With this result one can obtain the average bit error rate. We assume a modem bit error rate characteristic of the form

$$P_e = 1/2 \, e^{-\rho} \tag{2.100}$$

The average bit error rate is related to the Laplace transform (2.99) by

$$\overline{P}_e = \frac{1}{2} \left. \overline{e^{-s\rho}} \right|_{s=1} = \frac{1}{2} e^{-\sum_{k=1}^{K} u_k/(1+v_k)} \prod_{\ell=1}^{K} (1+v_\ell)^{-1} \tag{2.101}$$

Note that the average BER due to scatter alone is the product term in (2.101) so that we can write the average BER for mixed mode conditions as a weighted form of the scatter average BER, i.e.

$$\overline{P}_e = e^{-\sum_{k=1}^{K} u_k/(1+v_k)} \overline{P}_s \ , \ \overline{P_s} = 1/2 \prod_{\ell=1}^{K} (1+v_\ell)^{-1} \qquad (2.102)$$

and note the following energy relations

$$\sum_{k=1}^{K} u_k < a_D \overline{E}_b /N_0 \qquad)3)$$

$$\sum_{k=1}^{K} v_k < a_s \overline{E}_b/N_0 \qquad (2.104)$$

2.8.1.3 Fade Outage Probability, Troposcatter Propagation

The fade outage probability is defined as the probability that the instantaneous bit error rate exceeds a threshold value p given that the short term average SNR per bit $\overline{E}_b/N_0 = \gamma$, i.e., it is given by the conditional cumulative distribution

$$P_0(p/\gamma) = \text{prob}\{P_e > p/E_b/N_0 = \gamma\} \ . \qquad (2.105a)$$

however since the instantaneous bit error rate exceeds the threshold p when the effective SNR is below a threshold value, i.e., $\rho < r$, the outage probability is also given by

$$P_0(r/\gamma) = \text{prob}\ \{\rho < r/\overline{E}_b/N_0 = \gamma\} \tag{2.105b}$$

or by

$$P_0(r/\gamma) = \int_0^r f\left(x/\overline{E}_b/N_0 = \gamma\right)dx \tag{2.105c}$$

where the threshold SNR, r, is found from

$$p = \frac{1}{2}\, e^{-r}$$

i.e.,

$$r = \ell n(1/2p) \quad . \tag{2.106}$$

Evaluation of the outage probability requires that the conditional pdf of ρ, i.e., $f\left(x/E_b/N_0\right)$ be determined. The conditional pdf $f\left(x/E_b/N_0\right)$ can be found from its Laplace transform $F\left(s/E_b/N_0\right)$, i.e., Equation (2.77), using partial fraction expression techniques [Monsen, 1977]. For example if all of the K explicit diversity branches are uncorrelated (eg., 2S, 2S/2F, 2F), then we can write

$$F\left(s/\overline{E}_b/N_0\right) = \prod_{i=1}^{I}\left(1 + \frac{\overline{E}_b}{N_0}\,\lambda_i s\right)^{-K} = \sum_{j=1}^{K}\ \sum_{i=1}^{I} A_{ij}\left(1 + \frac{\overline{E}_b}{N_0}\,\lambda_i s\right)^{-j} \tag{2.107}$$

2.9.2 SNR Adjustment

The flow chart of subroutine TRC is given in Figure 2-14. The first essential task is to adjust the average received SNR for degradations due to the peak-to-average transmitted power ratio (PEAKAV), filtering (SNRBW), interference from other systems (SNRJAM) and interference from the 2nd frequency channel (SNRF2) for the AN/TRC-170 system. When a 99% bandwidth or FCC 19311 bandwidth constraint is specified, i.e., IBW >0, these parameters are computed in dB in subroutine FUNJAM. When IBW = 0 (no bandwidth constraint) only PEAKAV (computed in TRCIN) is taken into account. After converting the degradation parameters to decimal form the SNR loss is:

```
IF IBW =   0           SNRLOS = PEAKAV
IF IBW >   0
   TRCTYP =   0        SNRLOS = PEAKAV*SNRJAM*SNRBW
   TRCTYP =   1        SNRLOS = PEAKAV*SNRJAM*SNRBW*(1+SNR*SNRF2)
```

The SNRLOS is printed out in dB in the short term performance table. The actual detection SNR on which the performance is based is:

$$\text{Detection SNR} = SNR_0/SNRLOS$$

where

$$SNR_0 = \overline{E}_b/N_0$$

The computation of the SNR degradation due to co-channel or adjacent channel interference assumes that the interference power is the same on all diversity ports and that it is uncorrelated.

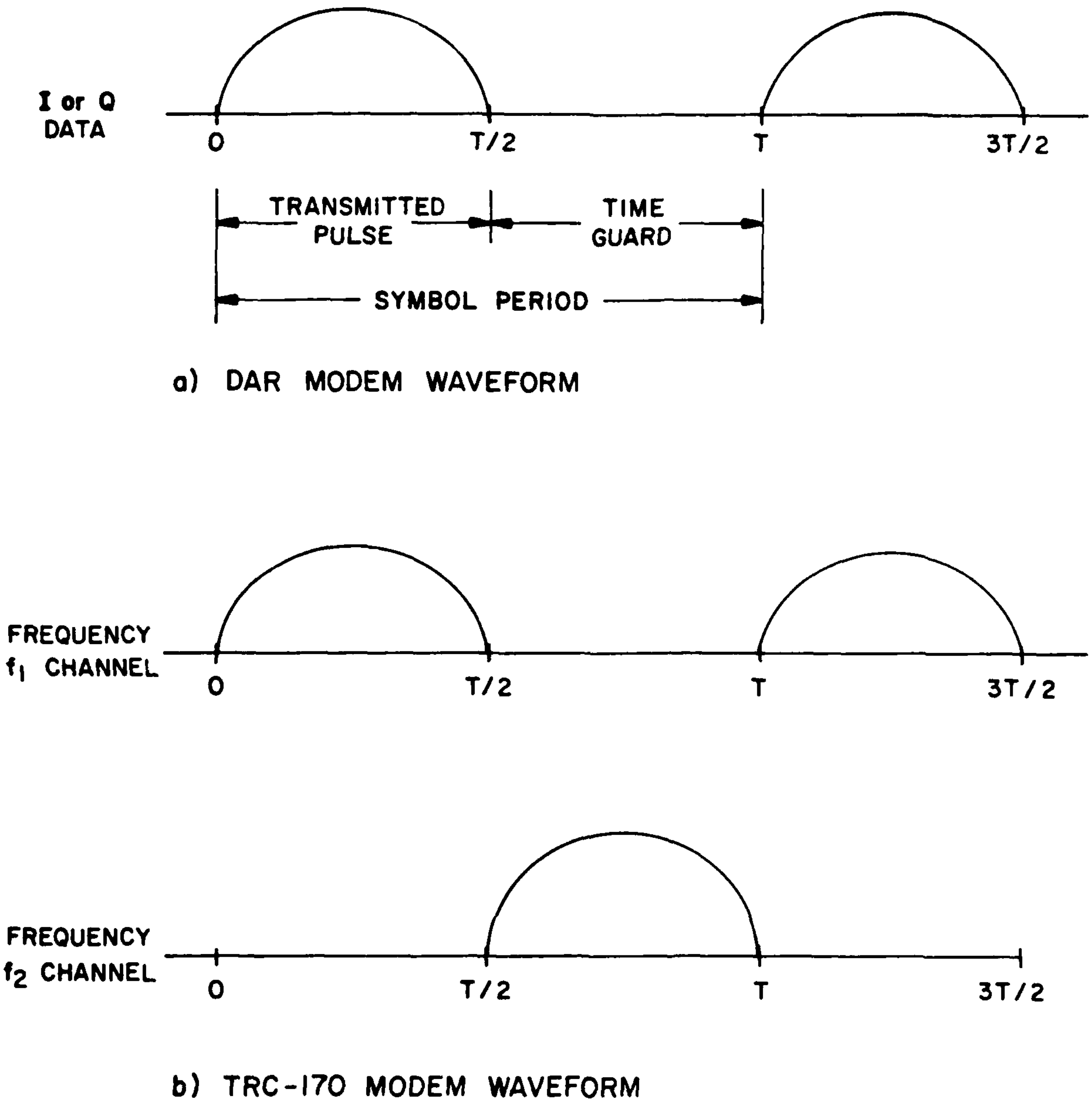
The data rate for which modem performance calculations are allowed must satisfy

$$\frac{BW}{4} < DRATE \leq BW$$

The input taken from the filtering/interference module (only for IBW >0) is:

TRFILT(·)	:	Tx-Rx filter impulse response
XTRINC	:	step between samples of TRFILT
XTRO	:	time origin of TRFILT
NTR	:	number of points of TRFILT
PEAKAV	:	peak-to-average power ratio of transmitted waveform in dB
SNRJAM	:	noise adjustment for co-channel or adjacent channel interference in dB
SNRBW	:	noise adjustment for finite bandwidth in dB
SNRF2	:	noise adjustment for interference due to 2 frequency transmission (AN/TRC-170 only) in dB

For IBW = 0, TRCIN assumes that the transmitted pulse is rectangular occupying half the symbol interval T, and that the Rx filter is an integrate and dump filter. It then computes the 99 percent transmission bandwidth and the peak-to-average power ratio (PEAKAV). After fixing various other TRC parameters, TRCIN calls TRC twice. First to compute the performance for quadruple diversity, which corresponds to a 2S/2F system, and secondly to compute the performance for dual diversity which corresponds to a 2S system. The yearly average fade outage and average fade-outage per call minute probabilities are passed to the SUMPAG file through BOUT(1) and FOUT(1) respectively.



I or Q DATA
0
T/2
T
3T/2
TRANSMITTED PULSE
TIME GUARD
SYMBOL PERIOD
a) DAR MODEM WAVEFORM
FREQUENCY f_1 CHANNEL
0
T/2
T
3T/2
FREQUENCY f_2 CHANNEL
0
T/2
T
3T/2
b) TRC-170 MODEM WAVEFORM

Figure 2-13

quency. Figure 2-13 shows the gated transmitted waveforms for the DAR and TRC-170 modems. In the following sections 2.9.1-5 we describe the general flow and the subroutine dependence of the various computations.

2.9.1 Input Requirements

The main subroutine for the performance computations is subroutine TRC. TRC requires input which i) is shared with other modules of TROPO, ii) depends on previously executed modules of TROPO (propagation, filtering/interference) and iii) is TRC-specific. The latter is useful for specialized applications. Subroutine TRCIN serves to interface TRC with the rest of TROPO and to automatically set most of the TRC-specific input to meet the objectives of the general TROPO user.

According to the present setting of TRCIN the only TRC-specific input which must be defined by the user is:

TRCTYP: = 1 for AN/TRC-170 modem,
= 0 for DAR modem.

The shared input data, also user defined, is:

LOUT:	output file switch
IBW:	filtering switch
DRATE:	data rate in bit/sec
NERT:	outage threshold switch
BW:	bandwidth in MHz

The input taken from the troposcatter propagation module is:

TAU22:	2σ multipath spread of troposcatter signal
ASNR:	yearly average SNR in dB
STSNR:	yearly standard deviation of SNR in dB

$$g(\Gamma_S) = \frac{1}{\sqrt{2\pi}\ \sigma_S} e^{-(\Gamma_S - M_S)^2/2\sigma_S^{\,2}}$$

$$g(\Gamma_D) = \frac{1}{\sqrt{2\pi}\ \sigma_D} e^{-(\Gamma_D - M_D)^2/2\sigma_D^{\,2}}$$

and M_S (coded ASNR) is the yearly median of the troposcatter component of the received SNR in dB, σ_S (coded STSNR) is its standard deviation, M_D (coded ADSNR) is the yearly median of the diffraction component of the received SNR in dB and σ_D (coded SDSNR) is its standard deviation.

2.9 AN/TRC-170 AND DAR MODEM PERFORMANCE

The AN/TRC-170 and DAR Modem performance is calculated by setting MODPAT=2. The modem performance calculations assume pure troposcatter propagation. The regular output consists of:

(i) the most significant implicit diversity eigenvalues,

(ii) the short term average (over the Rayleigh fading) bit error rate (ABER), fade outage per call minute and fade outage probability for received average SNR = -6 to +28 (dB) in 2 dB steps,

(iii) the yearly average fade outage and fade-outage per call minute probabilities

The theoretical analysis of the model used to approximate the performance of the AN/TRC-170 and DAR modems is given in the Final Report. The DAR and TRC-170 modems use QPSK modulation with a transmitter time gating technique and an adaptive matched filter receiver. The DAR modem is assumed to use a single frequency to transmit the data while the AN/TRC-170 uses a second frequency to transmit data during the off-time of the other fre-

conditional fade outage probability $P_0(r/\Gamma_i)$ for the threshold error rates of interest. The values of $P_0(r/\Gamma_i)$ should initially be small and increase toward unity. After $P_0(r/\Gamma_i)$ exceeds a threshold the procedure can be terminated and the yearly average fade outage probability approximated by

$$P_0(r) = \sum_{i=0}^{M} g(\Gamma_i)\; P_0(r/\Gamma_i) / \sum_{i=0}^{\infty} g(\Gamma_i) \quad . \tag{2.124}$$

Similar relationships hold for the yearly average fade outage per call minute and yearly average 1000 bit block error probability.

2.8.2.2 Mixed Mode Propagation

The long term average fade outage probability of the MD-918 where mixed-mode propagation takes place is obtained by averaging the short-term fade outage probability over the yearly distribution of the troposcatter and diffraction components of the received signal. If we assume that the long-term fading of the troposcatter and diffraction signal components is independent, the yearly average fade outage probability for a given SNR threshold r is given by

$$P_0(r) = \iint_{-\infty}^{\infty} P_0(r/\Gamma_S, \Gamma_D)\; g(\Gamma_S)\; g(\Gamma_D) d\Gamma_S\; d\Gamma_D \tag{2.125}$$

where

$$\Gamma_S = 10 \log a_S\, \overline{E}_b/N_0$$

$$\Gamma_D = 10 \log a_D\, \overline{E}_b/N_0$$

where $P_0(r/\Gamma)$ is the short term fade outage probability assuming a threshold error rate p and short-term average SNR per bit Γ in dB, and $g(\Gamma)$ is the long term pdf of Γ defined above in Equation (2.121).

In practice the calculation of the above integral (2.122) is difficult because each value of Γ requires a different partial fraction expansion solution to obtain $f(x/\Gamma)$. Fortunately, the conditional (short-term) fade outage probability $P_0(r/\Gamma)$ is a very steep function of Γ relative to the pdf $g(\Gamma)$ so that a relatively simple numerical integration routine should approximate $P_0(r)$, for the error rate thresholds p of interest, quite well. Of particular interest are the error rate threshold values $p = 10^{-3}$, 10^{-4} and 10^{-5} (coded BER(.)).

The numerical procedure used to estimate the yearly average fade outage probability $P_0(r)$, yearly average fade outage per call minute, and yearly average 1000 bit block error probability (coded BOUT(.,.), POUT(.,.), and ABE(.) in MDTS) is as follows. First find the value of Γ which results in a short-term average error rate $\overline{P_e}$ equal to or smaller than the threshold p. Call this value Γ_0. When $\Gamma = \Gamma_0$ the instantaneous BER, P_e, is most of the time much smaller than the average BER. Hence non-negligible values of $f(x/\Gamma)$ must occur when Γ is smaller than Γ_0. Then let the SNR decrease in steps of Δ dB, i.e.,

$$\Gamma_{i+1} = \Gamma_i - \Delta \quad i = 0, 1, 2, \ldots \tag{2.123}$$

and find the corresponding short-term fade outage probability $P_0(r/\Gamma_i)$, fade outage per call minute $P_{CM}(\Gamma_i)$ and 1000 bit block error probability $\overline{P}_b(\Gamma_i)$using the relationships given in Section 2.8.1. This involves finding for each Γ_i the eigenvalues λ_i corresponding to the diversity configurations of interest, finding the partial fraction expansion coefficients to invert the Laplace transform $F(s/\Gamma_i)$, determining the pdf $f(x/\Gamma_i)$ and obtaining the

2.8.2 Long-Term Performance

2.8.2.1 Troposcatter Propagation

The bit error rate and outage probabilities defined in the previous section are short-term performance measures valid over a period of time for which the average SNR per bit (averaged over the Rayleigh fading) is nearly constant. For troposcatter propagation this is the case for time periods of up to an hour. The long-term performance can be found by averaging over the long-term variations in $\overline{E}_b/N_0$. In troposcatter propagation these variations over a year are well described by the lognormal pdf (Gaussian if the SNR is expressed in dB)

$$g(\Gamma) = \frac{1}{\sqrt{2\pi}\,\sigma} e^{-(\Gamma-m)^2/2\sigma^2} \tag{2.121}$$

where $\Gamma = 10 \log \overline{E}_b/N_0$, m is the yearly median of the average SNR per bit in dB (coded ASNR in subroutine MDTS) and σ is the standard deviation of the average SNR in dB (coded STSNR in MDTS).

The yearly average fade outage probability for troposcatter propagation (coded BOUT(.,.) in MDTS) is then*

$$P_0(r) = \int_{-\infty}^{\infty} d\Gamma \int_0^r dx\ f\left(x/10 \log \overline{E}_b/N_0 = \Gamma\right) g(\Gamma)$$

$$= \int_{-\infty}^{\infty} P_0(r/\Gamma)\ g(\Gamma) d\Gamma,\ r=\ell n(1/2p) \tag{2.122}$$

---

* This calculation assumes that the multipath distribution can be approximated by its yearly median value.

$$P_b < \begin{cases} 1 & , \rho < \rho_b \\ 1000\ P_e(\rho) & , \rho > \rho_b \end{cases}$$

where $P_e(\rho_b) = .001$ or $\rho_b = 6.2$ (7.9 dB).

Averaging over the short-term fading statistics of ρ, we find the desired upper bound for the average 1000-bit block error probability, i.e.,

$$\begin{aligned}
\overline{P}_b &< \int_0^{\rho_b} f(x/\overline{E}_b/N_0)dx + 500 \int_{\rho_b}^{\infty} e^{-x} f(x/\overline{E}_b/N_0)dx \\
&= \int_0^{\rho_b} f(x/\overline{E}_b/N_0)dx + 500 \int_0^{\infty} e^{-x} f(x/\overline{E}_b/N_0)dx \\
&\quad - 500 \int_0^{\rho_b} e^{-x} f(x/\overline{E}_b/N_0)dx
\end{aligned} \tag{2.119}$$

For large $\overline{E}_b/N_0$, (2.119) is upper bounded by the second term which is equal to 1000 times the average bit error rate, i.e.,

$$\overline{P_b} < 500\ F(1/\overline{E}_b/N_0) = 1000\ \overline{P_e} \tag{2.120}$$

where $F(s/E_b/N_0)$ is the Laplace transform of the conditional pdf of ρ, defined in Equation (2.77). This upper bound (Eq. (2.120)) is used in TROPO to estimate the average 1000-bit block error probability. A tighter upper bound can be obtained by evaluating all three terms in (2.119).

2.8.1.6 1000-Bit Block Error Probability

At a particular instant of time, the probability of a 1000-bit block error is given by

$$P_b = 1 - [1 - P_e(\rho)]^{1000}$$

$$= \sum_{n=1}^{1000} a_n (-1)^{n+1} P_e^{\,n} \ , \quad a_n = \frac{1000!}{n!(1000-n)!}$$

where P_e is the instantaneous bit error rate, i.e., $P_e = .5 \exp(-\rho)$ and ρ is the effective instantaneous SNR.

If the 1000-bit block duration is much less than the fade duration (data rate much greater than the fade rate), then the average 1000-bit block error probability is given by the average over the short-term statistics of ρ, i.e.,

$$\overline{P}_b = \sum_{n=1}^{1000} a_n (-1)^{n+1} \int_0^{\infty} \left(\frac{1}{2}\right)^n e^{-nx} f(x/\overline{E}_b/N_0)\, dx$$

$$= - \sum_{n=1}^{1000} a_n \left(- \frac{1}{2}\right)^n F(n/\overline{E}_b/N_0)$$

where $F(n/\overline{E}_b/N_0)$ is given by Eq. (2.77). All 1000 terms in this expression must be evaluated, even for large $\overline{E}_b/N_0$, in order to determine the average 1000-bit block error probability correctly. An upper bound can be obtained as follows.

An upper bound to the instantaneous block error probability is

where r_m satisfies the relation

$$e^{-\sum_{k=1}^{K} u_k/v_k} Q_0(r_m) = Q_0(r_m - a_D \overline{E}_b/N_0) \qquad (2.117)$$

The approximation is appropriate since the outage probability averaged over long term fading of the diffraction and scatter component will be dominated by the small r and strong scatter (v_k generally large) case for which the approximation (2.116a) is good.

2.8.1.5 Fade Outage Per Call Minute

The fade outage per call minute is defined as the probability of one or more outages of duration less than 5 seconds in a one minute interval [Kirk and Osterholz, 1976]. Mathematically this can be expressed as

$$P_{CM} = 1 - (1-P_0)^{12} \qquad (2.118)$$

where $1-P_0$ is the probability of no outages in a time interval of 5 seconds. Since typical troposcatter fading rates are in the order of 1 Hz and the data rates of interest are in the order of 1 Mb/sec, a good measure of P_0 is given by the outage probability defined in Equation (2.110).

$$P_0(r) \doteq e^{-\sum_{k=1}^{K} u_k/v_k} Q_0(r) \qquad r \ll \overline{E}_b/N_0 \qquad (2.114a)$$

where $Q_0(r)$ is the outage probability due to scatter alone, viz.,

$$Q_0(r) = \frac{1}{2\pi j} \int_{-j\infty+\sigma}^{j\infty+\sigma} e^{sr} \prod_{k=1}^{K} (1+sv_k)^{-1} \, ds/s \qquad (2.114b)$$

For large r (small s in the transform domain) we have

$$P_0(r) \doteq Q_0(r-a_D\overline{E}_b/N_0) \qquad r > \overline{E}_b/N_0 \qquad (2.115)$$

For purposes of numerical integration over the parameter $\overline{E}_b/N_0$ to obtain the average fade outage probability corresponding to a long interval such as a year, one can approximate $P_0(r)$ by the piece-wise function

$$\rho_0(r) \doteq \begin{cases} e^{-\sum_{k=1}^{K} u_k/v_k} Q_0(r) & r \leq r_m \qquad (2.116a) \\ \\ Q_0(r - a_D\overline{E}_b/N_0) & r > r_m \qquad (2.116b) \end{cases}$$

2.8.1.4 Fade Outage Probability, Mixed Mode Propagation

The fade outage probability is defined as the probability that the BER is greater than a threshold p_t which is equivalent to the probability that the SNR ρ is less than a threshold r where

$$r = -\ln(2p_t) \tag{2.111}$$

Thus the outage probability is defined in terms of the inverse Laplace transform,

$$P_0(r) = \frac{1}{2\pi j} \int_0^r dx \int_{-j\infty+\sigma}^{j\infty+\sigma} e^{sx}\, \overline{e^{-s\rho}}\, ds \quad . \tag{2.112}$$

Since integration is equivalent to division by s in the transform domain, we have

$$P_0(r) = \frac{1}{2\pi j} \int_{-j\infty+\sigma}^{j\infty+\sigma} e^{sr}\, \overline{e^{-s\rho}}\, ds/s \ . \tag{2.113}$$

One can find the outage probability from (2.99) and (2.113) directly by expanding the exponential in (2.99) in a series and performing partial fraction expansions. For asymptotic results we deduce the following. For small r (large s in the transform domain) we have

where the A_{ij} are the partial fraction expansion coefficients (calculated in subroutine PDFCON)*. The pdf corresponding to (2.107) is then given by

$$f\left(x/\overline{E}_b/N_0\right) = \sum_{j=1}^{K} \sum_{i=1}^{I} A_{ij} \frac{U_i\left(U_i x\right)^{j-1}}{(j-1)!} e^{-U_i x} \tag{2.108}$$

where

$$U_i = \frac{N_0/\overline{E}_b}{\lambda_i} \tag{2.109}$$

Substituting (2.108) in (2.106) and integrating we get the desired expression for the outage probability

$$P_0\left(r/\overline{E}_b/N_0 = \gamma\right) = 1 - \sum_{i=1}^{I} \sum_{j=1}^{K} A_{ij} e^{-U_i r} \sum_{n=1}^{j} \frac{\left(U_i r\right)^n}{n!} \tag{2.110}$$

where use has been made of the fact that the partial fraction expansion coefficients must add up to unity.

---

* NOTE: Depending on the diversity configuration, some of the explicit diversity branches will be correlated so that (2.107) will have a similar form but the values of I and K will differ.

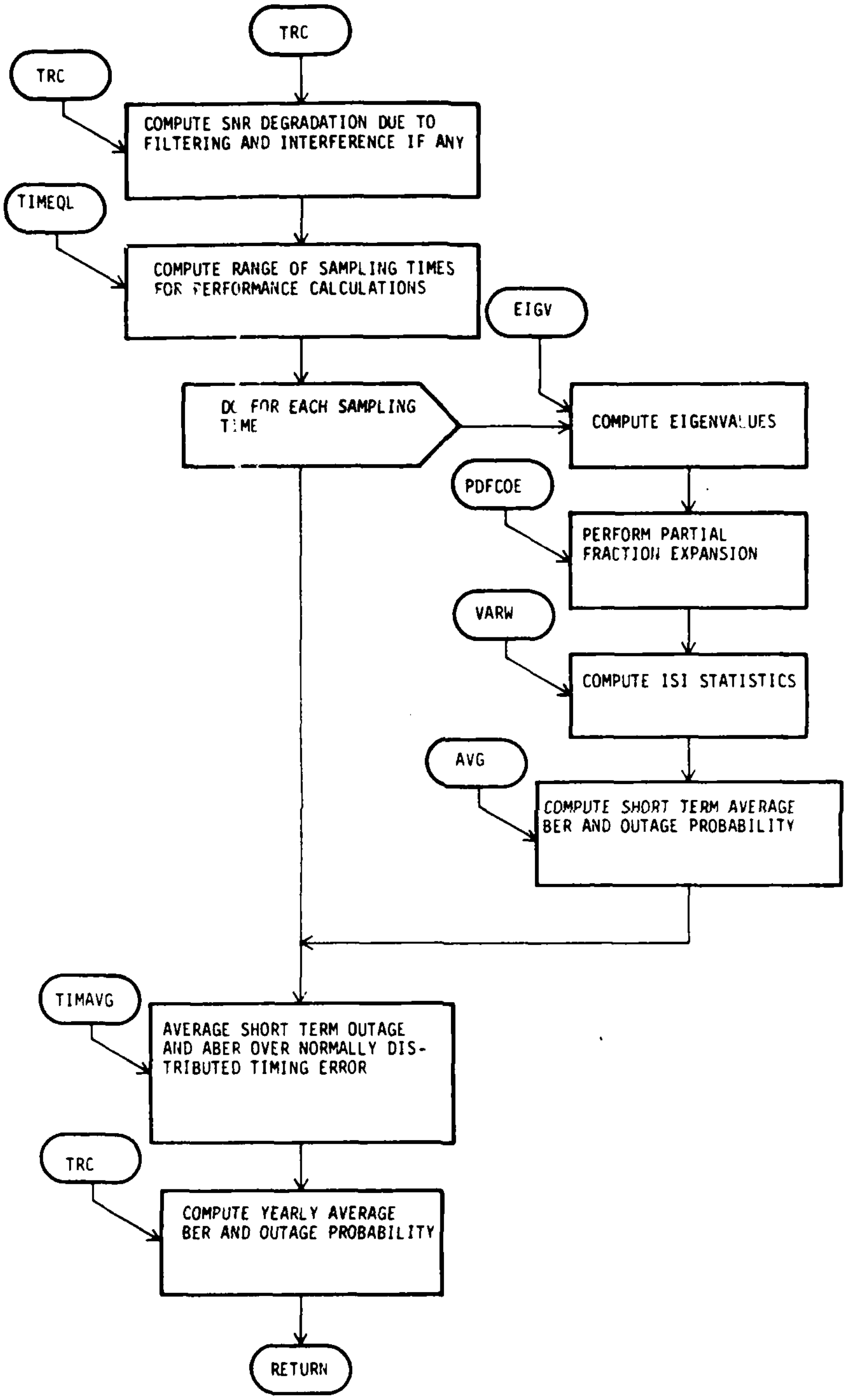


Figure 2-14 Flow Chart for AN/TRC-170-DAR Modem Performance Calculations

2.9.3 The Sampling Time

The sampling time refers to the parameter t_0 of the final report, which adjusts the sequence of sampling and decision instants over the received waveform. Its code name is T0. We have found that even for moderate multipath spreads relative to the symbol interval, i.e., $2\sigma/T > .3$, the performance is affected very much by the selection of t_0. The effect is more prominent in the 2S/2F system than in the 2S system and becomes stronger as the multipath spread increases. A switch IOTIME is used to indicate whether one or more different sampling times considered in the performance calculations are taken into account. With the presently set value IOTIME = 2, an estimate of the average sampling time is computed, on the basis of an early-late technique reported in [Unkauf, et al., 1979] for the phase error estimator circuit. This is done in subroutine TIMEQL and the estimate is stored in TEQL. TEQL is the solution of $f(x) = 0$ where:

$$f(x) = \iint R_h(u+x)\, R_h(v+v)\, J(u,v)\, du dv$$

$$J(u,v) = \left[\int_0^{T/2} p(t-u)\, p(t-v)\, dt \right]^2 - \left[\int_{T/2}^{T} p(t-u)\, p(t-v)\, dt \right]^2$$

where $p(t)$ is the impulse response of the cascade of the transmitter and receiver filters, i.e.,

$$p(t) = p_t(t) * p_r(t)$$

and $R_h(t)$ is the power per unit delay multipath profile of the troposcatter signal. The sampling time t_0 is assumed to be distributed normally around TEQL with standard deviation TDEV=0.05T. The short term performance is then computed for 7 values of t_0:

TEQL-3*TDEV,..., TEQL+3*TDEV and finally averaged with respect to t_0. The values of t_0 are stored in array TOTO(•). It should be noted that since the signal and ISI statistics depend on t_0 this approach implies that essentially the computational requirements increase 7-fold.

2.9.4 Statistics of Detection Variables

If the transmitted information sequence in one frequency channel of the system is $S_k = a_k + jb_k$, a_k, $b_k = \pm 1$, the detection variable in the in-phase channel and for the mth symbol is given by

$$\tilde{a}_m = a_m \overline{E}_b^{1/2}\gamma + \overline{E}_b^{1/2} \sum_{k=\pm 1} (\alpha_k a_{m-k} + \beta_k b_{m-k}) + n_d$$

The signal gain γ and the ISI weights α_k, β_k fluctuate ramdomly over intervals larger than the coherence time (~.1 sec for the tropospheric scatter channel). Their joint statistics are required to determine the short-term performance. The effective detection noise n_d has power denisty $\gamma N_d/2$, where N_d is the adjusted thermal noise density N_0 discussed in Section 2.9.2. The average received signal energy per bit $\overline{E}_b/N_0$ fluctuates over intervals larger than 1 hour. Its statistics are required to determine the long-term or yearly system performance. It is assumed that $\overline{E}_b/N_0$ has a log-normal distribution. The mean ASNR and the standard deviation STSNR are calculated in the propagation module and passed to TRC. After the short-term performance has been obtained, the computation of the yearly average performance is the same as with the MD-918 modem (Section 2.8.2). In the remainder of this section we describe the specification of the joint statistics of γ, $\alpha_{\pm 1}$ and $\beta_{\pm 1}$ and in Section 2.9.5 we describe how these statistics are employed to compute the short term performance.

The random variables γ, $\alpha_{\pm 1}$, $\beta_{\pm 1}$ are assumed independent and moreover $\alpha_{\pm 1}$, $\beta_{\pm 1}$ are assumed normal. The probability density function of the signal gain has the form,

$$\mathrm{pdf}(\gamma) = \sum_{i=1}^{D} \sum_{j=1}^{N'} A_{ij}(\underline{\lambda})\, G_i(\gamma, \lambda_j) \; .$$

where D (coded NDIVS) is the number of the independent diversity channels. The parameters λ_j (coded VEIGV(•)) are the eigenvalues of the covariance matrix V (coded V(•,•) of dimension NxN with elements defined as

$$V_{m,n} = \frac{T}{N} \int p\left(\frac{mT}{N} - u\right) p\left(\frac{nT}{N} - u\right) R_h(u + t_0)\, du \; .$$

where N (coded NV) is an empirically determined parameter to approximate the non-diversity signal gain as a sum (presently N = 18). The eigenvalues are computed in the subroutine EIGV, p(t) is on the transmitter-receiver pulse computed in the function TXPULS, $R_h(t)$ is the multipath profile computed in the function PROFIL according to the approximation:

$$R_h(t) = b^2 t e^{-bt}, \; b = \sqrt{2/\sigma} \; .$$

The normalized multipath spread σ/T (coded SIGMA) is computed in subroutine TRCIN given 2σ (coded TAU22) and the data rate (coded DRATE). As a general rule the time variable t, in TRC is always normalized with respect to the symbol interval T:

T = 2/DRATE :single frequency DAR

T = 4/DRATE :two-frequencies AN/TRC-170

Once V has been set up, the eigenvalues are computed by invoking the subroutines ELMES and HQR. The sum of the eigenvalues is upper bounded by 1:

$$\sum_{i-1}^{N} \lambda < 1$$

The eigenvalues are ordered in decreasing order, the first N' (coded NEIGEN) are preserved to approximate pdf(γ) and the rest neglected. Presently N' is chosen so that:

$$N' > 3$$

$$\lambda_{N+1} < 0.05 \ \lambda_1 = 0.05 \ \lambda_{max}$$

Finally the first N' eigenvalues are compensated to preserve the sum value:

$$\lambda_j \text{ replaced by } \lambda_j \left(\sum_{k=1}^{N} \lambda_k \right) / \left(\sum_{k=1}^{N'} \lambda_k \right)$$

which is equal to the average signal gain.

Coming back to the pdf(γ) we note that the function $G_i(x,\lambda)$ is the ith order gamma density with parameter γ:

$$G_i(x,\lambda) = \frac{1}{\lambda^i (i-1)!} x^{i-1} e^{-x/\lambda}, \quad x>0$$

The coefficients $A_{ij}(\underline{\lambda})$ are the partial fraction expansion coefficients of the Laplace transform of pdf(γ)

$$PDF(s) = \prod_{j=1}^{N'} \frac{1}{(1+\lambda_j s)^D} = \sum_{i=1}^{D} \sum_{j=1}^{N'} A_{ij}(\underline{\lambda}) \frac{1}{(1+\lambda_j s)^i}$$

The coefficient A_{ij} can be obtained by the formula:

$$A_{D-i,j} = \frac{1}{\lambda_j{}^i i!} \frac{d^i}{ds^i} \prod_{k(+j)=1}^{N'} \frac{1}{(1+\lambda_k s)^D} \quad s=-1/\lambda_j$$

This computation is done in subroutine PDFCOE and the coefficient stored in array COEFF(1). After the eigenvalue, and the partial fraction expansion coefficients have been specified pdf(γ) is computed from the function PDF.

Regarding the ISI weights $\alpha_{\pm 1}$, $\beta_{\pm 1}$ the Gaussian model requires that their mean and variance be known. The mean turns out to be zero. The variance is,

$$\mathrm{var}(\alpha_k) = \mathrm{var}(\beta_k) \approx \frac{D}{2} \iint R_h(u+t_0)\, R_h(v+t_0)\, I^2(u,v-kt)\, dudv$$

where,

$$I(x,y) = \int_0^T p(t-x)\, p(t-y)\, dt$$

The variances are computed in the function VARW. The integral I is computed in the function P2INT. The larger of the variances is stored in VARAIS and the smaller in VARBIS.

If the computation of the statistics of γ fails, the short-term modem performance computations are skipped and the performance set to the value 10.

2.9.5 Short Term Modem Performance

The instantaneous bit error rate P_e of the system, including ISI effects, is given by [from Appendix A of the Final Report]

$$P_e(\gamma,\underline{\gamma}_I) = \frac{1}{2} \cdot \frac{1}{16} \sum_{\ell=1}^{16} \mathrm{erfc}\left[(\bar{E}_b\gamma/N_d)^{1/2}(1 + \underline{\gamma}_I \underline{S}_I(\ell)/\gamma)\right] .$$

where erfc(•) is the complimentary error function:

$$\mathrm{erfc}(x) = \frac{2}{\sqrt{\Pi}} \int_x^{\infty} e^{-u^2}\, du$$

$\underline{\gamma}_I$ is the vector of the ISI weights:

$$\underline{\gamma}_I = (\alpha_1,\ \beta_1,\ \alpha_{-1},\ B_{-1})^T$$

$\underline{S}$ is the vector of the symbols which are adjacent to the currently detected mth symbol:

$$\underline{S}_I = (a_{m-1}, b_{m-1}, a_{m+1}, b_{m+1})^T$$

The index ℓ in $\underline{S}_I(\ell)$ indicates one out of the 16 possible ISI symbol combinations:

ℓ	$\underline{S}_I$			
1	1	1	1	1
2	1	1	1	-1
3	1	1	-1	1
.				
.				
.				
16	-1	-1	-1	-1

The performance measures we are interested in are the average bit error rate P_{avg}:

$$P_{avg} = \int_0^\infty \left[\iiint P_e(\gamma, \gamma_I)\, pdf(\gamma, \gamma_I) d\underline{\gamma}_I\right] d\gamma$$

and the fade outage probability P_{out} for a bit error rate threshold p_t:

$$P_{out} = \underset{\Gamma}{\iiiint} pdf(\gamma, \underline{\gamma}_I)\, d\gamma d\gamma_I$$

$$\Gamma = \{(\gamma, \underline{\gamma}_I) : P_e(\gamma, \underline{\gamma}_I) > p_t\} .$$

For both P_{avg} and P_{out} we break the computation into two steps. First we compute the conditional performance for a fixed value of

the signal gain. Since $\underline{\gamma}_I$ was assumed independent of γ this amounts to:

$$P_{avg}(\gamma) = \iiint P_e(\gamma, \underline{\gamma}_I)\, pdf(\underline{\gamma}_I)\, d\underline{\gamma}_I$$

$$P_{out}(\gamma) = \iiint_{\Gamma(\gamma)} pdf(\underline{\gamma}_I)\, d\underline{\gamma}_I$$

$$\Gamma(\gamma) = \{(\underline{\gamma}_I) : P_e(\gamma, \underline{\gamma}_I) > p_t\} .$$

The short term performance then is computed by averaging with respect to the signal gain:

$$P_{avg} = \int_0^\infty P_{avg}(\gamma)\, pdf(\gamma)\, d\gamma$$

$$P_{out} = \int_0^\infty P_{out}(\gamma)\, pdf(\gamma)\, d\gamma .$$

The second step is straight forward and is performed in the subroutine AVG. When AVG is called from TRC it is provided with one of the subroutines PAVERG or POUTAG, which compute correspondingly $P_{avg}(\gamma)$ and P_{out}. P_{avg} is stored in the array PAVG $(\cdot,\cdot)$, where the first argument stands for the received average SNR and the second argument stands for the sampling time. Recalling our previous discussion, the computation of short term performance for different sampling times is required in order to average out

effects of timing jitter. On the other hand the computation of the short term performance versus various SNR's, besides being informative in itself is required for averaging over the long term fluctuations of the SNR to find the yearly performance. The fade outage probability P_{out} is stored in the array POUT $(\cdot,\cdot,\cdot)$, where the first two arguments have the same significance as in PAVG $(\cdot,\cdot)$ and the third argument indicates the bit error rate threshold P_t. Currently the program is set up to compute outage probabilities for the instantaneous bit error rate thresholds 10^{-3}, 10^{-4}, 10^{-5}.

To complete the exposition of the computational procedure we need to describe how the conditional performance $P_{avg}(\gamma)$ and $P_{out}(\gamma)$ is obtained. A review of the relevant formulas indicates that this computation is very inefficient if done in a straightforward manner because of the dimensionality of the computations. After considerable theoretical manipulations, contained in the final report, we have reduced the required computations so that presently the calculation proceeds in the following way:

i. Conditional average probability of error $P_{avg}(\gamma)$ is computed in the subroutine PAVERG and stored in AVGISI. It is given by

$$2P_{avg}(\gamma) = \sqrt{y}\, \exp[-\gamma y(\bar{E}_b/N_d)] + \operatorname{erfc}[\gamma/\sigma_I\sqrt{2}]$$

where

$$y = \frac{\gamma}{2(\bar{E}_b/N_d)\ \sigma_I^2 + \gamma}$$

and

$$\sigma_I^2 = \operatorname{var}(\alpha_1) + \operatorname{var}(\beta_1) + \operatorname{var}(\alpha_{-1}) + \operatorname{var}(\beta_{-1}) .$$

The parameter σ_I^2 is stored in VARISI.

ii. Conditional fade outage probability. A tight upper bound of $P_{out}(\gamma)$ is computed in the subroutine POUTAG and stored in OUTISI. For $\gamma < \gamma_{min}$ $P_{out}(\gamma)=1$. The parameter $\gamma_{min} \cdot \overline{E}_b/N_0$ is the solution of the equation

$$\frac{1}{2}\,\mathrm{erfc}(\sqrt{x}) = p_t \;.$$

It is coded on RSNMIN(•) where the argument indicates the threshold p_t. RSNMIN(•) has been computed outside the program and passed by a DATA statement to TRC. For $\gamma > \gamma_{min}$ we have

$$P_{out}(\gamma) \lesssim 1 - \sum_{i=1}^{K} g_1\big((i-1)\delta_L,\ i\delta_L\big) \cdot \sum_{j=1}^{K=1} g_1\big((j-1)\delta_L, j\delta_L\big)$$

$$\cdot \sum_{k=1}^{K-i-j} g_{-1}\big((k-1)\delta_L,\ k\delta_L\big) \cdot \sum_{\ell=1}^{K-i-j-k} g_{-1}\big((\ell-1)\delta_L, \ell\delta_L\big) \;.$$

The function $g_i(u,v)$ is defined as:

$$g_i(u,v) = \mathrm{erfc}\Big[\frac{u}{(2\ \mathrm{var}(\alpha_i))^{1/2}}\Big] - \mathrm{erfc}\Big[\frac{v}{(2\ \mathrm{var}(\alpha_i))^{1/2}}\Big]$$

and it is stored in the array DA(•) for the index i = ±1, which yields the largest var (α_i), and in the array DB(•) for the other index. The parameter K (coded KISI) is presently set to 6.

The parameter δ_L is defined as:

$$\delta_L = \frac{1}{K}\ \alpha_L(\overline{E}_b/N_d,\ \gamma)$$

$$\alpha_L(\overline{E}_b/N_0,\ \gamma) = \gamma \cdot \alpha_L(\gamma \cdot \overline{E}_b/N_d,\ 1)$$

where $\alpha_L(\rho,\ 1)$ is the solution of the equation:

$$8 \cdot f_1(x) = p_t$$

$$f_1(x) = \frac{1}{2} \cdot \frac{1}{16}[\exp[-\rho(1-x)^2] + \exp[-\rho(1+x)^2]]$$

The function $\alpha_L(\rho,1)$ has been computed for 30 ρ-points and for the 3 thresholds of interest and is passed by a DATA statement to TRC coded as UPISIM(•,•). For a particular ρ, $\alpha_L(\rho,1)$ is obtained by interpolation in the array UPISIM. The parameter $\alpha_L(E_b/N_d,\ \gamma)$ is coded as UPISI. The parameter δ_L is not coded directly. Instead for the largest var(α_i), i = ±1, the parameter $\delta_L/(2\ \mathrm{var}(\alpha_i))^{1/2}$ is stored in XA and for the smaller var(α_i) the previous parameter is stored in XB.

2.10 TROPOSCATTER CHANNEL SIMULATOR SETTINGS

TROPO also calculates the settings of a tapped delay line troposcatter channel simulator so as to reproduce the same power per unit delay profiles and correlation per unit delay calculated or a dual diversity path.

The troposcatter channel simulator is assumed to be a dual diversity simulator with N-taps per diversity and tap spacing T. The number of taps, N, and tap spacing, T, can be arbitrarily

specified. The impulse response of each simulator diversity channel is given by

$$h_k(t) = \sum_{i=1}^{N} W_{ki}\,\delta(t-iT), \quad k=1,2$$

where the simulator tap gains W_{ki} are determined as follows.

The total received power for the kth diversity channel is equal to the sum of the mean squared tap gains, i.e.,

$$P_k = \int_{-\infty}^{\infty} \overline{|h_k(t)|^2}dt = \sum_{i=1}^{N} \overline{|W_{ki}|^2} .$$

The received power can also be expressed in terms of the integral of the power per unit delay profile calculated by TROPO as

$$P_k = \sum_{n=1}^{NDEL} Q_k(n\tau)$$

where $Q_k(.)$ is the power per unit delay profile calculated for the kth diversity channel, NDEL is the number of delay cells (less than 100) and τ is 'width' of each delay cell.

The mean-squared tap gains for the kth diversity channel are calculated as

$$\overline{|W_{ki}|^2} = \sum_{j=J1}^{J2} \alpha_j Q_k(j\tau), \qquad i=1,\ldots,N$$

where

$$\alpha_j = 1 - \frac{|j-J0|}{T_\tau+1}$$

$$J0 = \left\lfloor i \frac{T}{\tau} + 1 \right\rfloor$$

$$J1 = \left\lfloor (i-1) \frac{T}{\tau} + 1 \right\rfloor$$

$$J2 = \left\lfloor (i+1) \frac{T}{\tau} + 1 \right\rfloor$$

and where $\lfloor . \rfloor$ denotes integer part of the quantity inside the brackets. The tap gains are then normalized so that the target tap gain is unity (0 dB).

The correlation between the gains on the two diversity channels is determined from the relationship

$$W_{1i}W^*_{2i} = \sum_{j=J1}^{J2} \alpha_j \; Q_{12}(j\tau)$$

where $Q_{12}(j\tau)$ is the correlation per unit delay profile calculated by TROPO for the path specified and J1 and J2 are defined above.

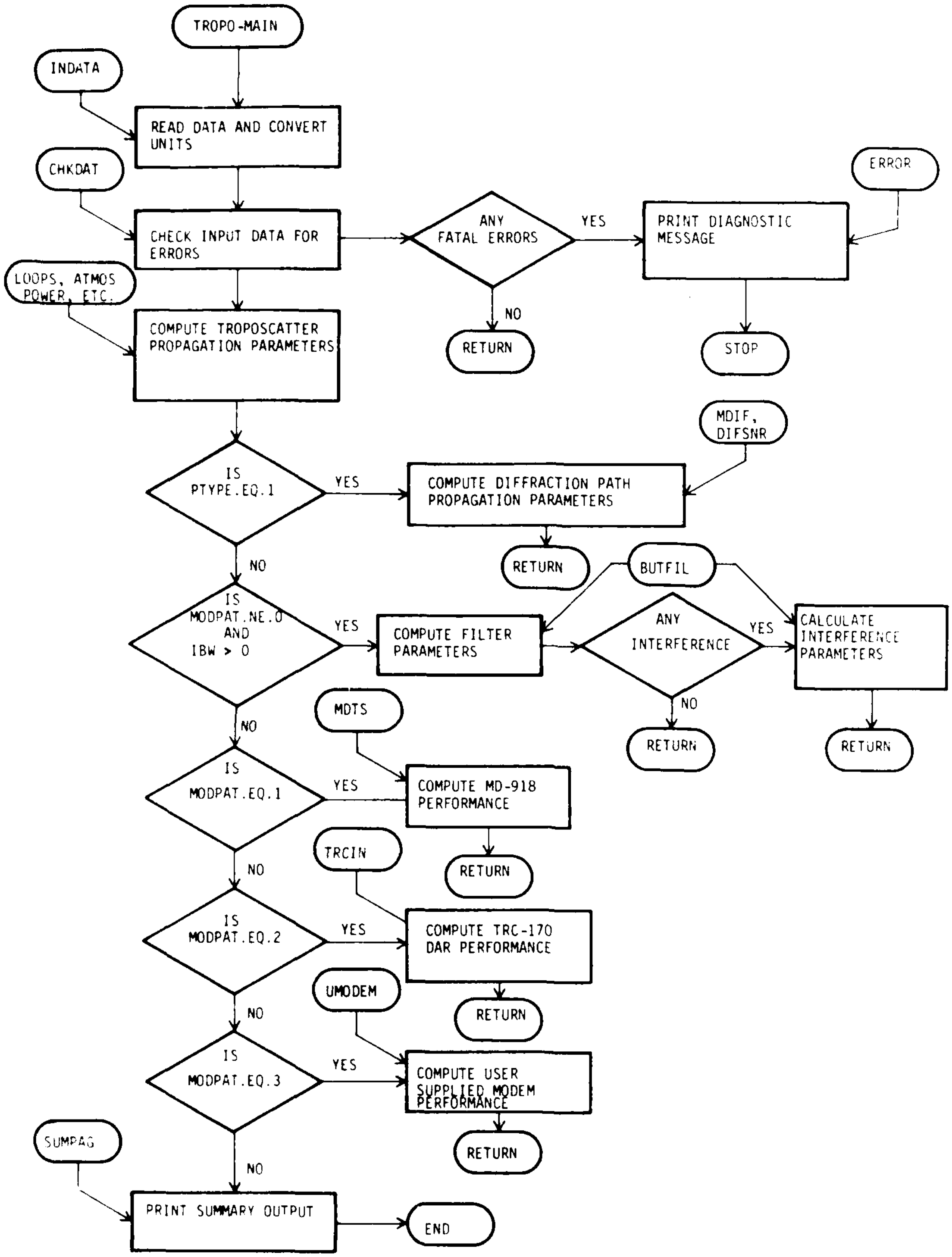


Figure 3-4 Top Level Functional Flow Chart for TROPO Program Calculations

The first line of the file is the keyword "START", and the last line is the keyword "END". Other keywords are used as described below to mark sections of the file. If a section is not used because of program options (e.g., no modem because MODPAT = 0), it can be omitted. If an unused section is nevertheless included, the superfluous data will be skipped. The keywords preceding the sections actually used, however, must be present. All keyword lines are entered left-justified. The program checks the first 4 character positions of the line to identify the keyword. Figure 3-4 illustrates the logical flow of input file processing.

Program Control Parameters:

START (mandatory keyword).

LNAME(20)	Link name (Tx site first, Rx site second), 40 characters maximum, 20A2 format, left justified.
MODPAT	Propagation/Modem calculations indicator (default = 1)

0 = Propagation only
1 = Propagation + MD-918 modem
2 = Propagation + AN/TRC-170 modem
3 = Propagation + user-defined modem

A separator is either a comma or space(s) (or, on PDP systems, a tab). It may be surrounded by any number of spaces or carriage returns. A slash (/) separator causes termination of processing on the input record. All remaining list elements remain unchanged.

The defaults expressed in the input parameter definitions are those assumed by the program when a null value or slash (/) is specified instead of an actual data value.

The total number of data items entered must be what the program expects or an error condition will result. In this case, TROPO or the operating system will print a message which indicates the point at which the problem became apparent. The actual cause of the problem can normally be discovered and corrected by careful inspection of the indicated part of the input file.

The input parameters, their order of input, and their meanings are described below. Where a "default" value is mentioned, this value will be assumed whenever the input value is omitted (according to standard Fortran IV list-directed input rules). When a number or variable name in parentheses follows the input variable name, this indicates the number of data values expected for the input unless otherwise noted.

The reader should refer to the sample input file (which is a concatenation of three files) listed in Section 4 when reading through this section. These files are included on the TROPO tapes, and it is suggested that new users run at least one of them initially to verify that a successful run can be obtained with the indicated file format. Then, problems of interest to the user can be set up by modifying a working input file using a standard system text editor. It is recommended that each TROPO user carefully read through the descriptions given below before attempting to set up a new or modified TROPO input file.

otherwise not used, therefore the content is not as important as their presence. They serve to help the user to find the proper lines at which to make modifications, and to interpret the meaning of the data lines. (See Section 4 for listings of several example input files.)

The data itself is read according to Fortran "list-directed input" rules (with a few exceptions - see remarks on literals in the next paragraph). Refer to your system's reference manuals for complete details; a brief summary follows.

List-directed input data consists of an alternation of constants and separators. An input constant may be any Fortran data type except literal for the PDP-11. For the IBM 370, literals must be enclosed in quotation marks. For compatibility of the input program with both computers, literals are in alpha-numeric (An) format.

Each constant must agree in type with the corresponding list element. The decimal point may be omitted from a floating-point constant (if omitted it is assumed to follow the rightmost digit).

A null value is represented by two consecutive commas with no intervening constant. Spaces can be embedded between the commas. A null value specifies that the corresponding list element is to remain unchanged. A null value cannot be used for either part of a complex constant but may represent an entire complex constant.

Constant repetition data input is of the form n*C where n is a non-zero, unsigned integer constant and C is the input constant.

3.1.3 Major FORTRAN Differences Between the PDP-11/70 and IBM Versions of TROPO

	FORTRAN IV-PLUS (PDP)	FORTRAN IV-H (IBM)
PARAMETER Statement	YES	NO
INCLUDE Statement	YES	NO
BYTE Data Type	YES	NO
TAB Character	YES	NO
Blank Lines	YES	NO

3.2 INPUT FILE FORMAT

TROPO is designed to obtain all variable data for a run from a single input file, which must be in a precise format, as described below. The primary source of difficulty with getting TROPO to run properly is incorrect input file format or incorrect or inconsistent data in the file. The user is therefore urged to read this section carefully and to check over his input file line by line to verify that it is correct before attempting a run. This is especially important when the file is totally new or when major changes have been made, or when a run has produced error messages. Once a successful run has been obtained, subsequent runs with parameter changes can usually be accomplished with relative ease.

TROPO performs some input data checking, and produces error messages when error conditions are detected. Section 3.4.3 summarizes the TROPO messages and suggests most likely causes and cures. Your computer system may from time to time take matters into its own hands and issue an error message not under TROPO's control.

The TROPO input file consists of keyword lines and a variable number of explanatory comment lines (beginning with *), interspersed with data lines. The comment lines are read but

Figure 3-3

PDP Build Files

Task Build Command File TKBTROPO.CMD

```
TROPO=TROPO/MP
;
; The assignment
;                  ASG=TI:4
; causes TROPO errors directed to the variable logical unit number
; LTERM to be output to the user's terminal.  (LTERM is associated
; with unit 4 by data statement in TROPO.)
; If the terminal cannot be used for output for some reason, unit 4
; can be reassigned to the system disk by the explicit statement
;                 ASG=SY:4
; which will open a FOR004.DAT file for the error messages or
; implicitly, by omitting the 'ASG' altogether.
; In either case, the maximum number of units open at any one time,
; ACTFIL, remains 4 and the highest numbered unit, UNITS, remains 4.
;
ASG=TI:4
UNITS=4
ACTFIL=4
/
```

Figure 3-2 PDP Build Files
Overlay File TROPO.ODL

```
;       Links explicitly to F4POTS.OLB in order to use F4P rather than
;       F77, which is the system default at this time.  'LIB' linkage can
;       be eliminated if F4P modules are the SYSLIB.OLB default.
;
 ROOT TROPO-LINKS-LIB-*(IO,GEO,LO,DIF,BUT,MDT,TR)
;
;       DATAINIT is a block data subprogram.  SHORT is the short error module.
;
LINKS:  .FCTR ERROR-DATAINIT-SUBID-LB:[1,1]F4POTS/LB:$SHORT
LIB:    .FCTR LB:[1,1]F4POTS/LB
;
;       Input, data checking, and output branch:
;
IO:     .FCTR (I,CK,O)
I       .FCTR INDATA-LIB-((ERRIO-UNITCV-UNITS-LIB),(ANTGEO-LIB),(OUTDAT-LIB))
CK:     .FCTR CHKDAT-LIB
O:      .FCTR SUMPAG-UNITCV-SIM-ANTPTR-LIB
;
;       Path geometry and diffraction branch (both access HORANG):
;
GEO:    .FCTR HORANG-LIB-((ATMOS-TRANSF-ANTPAR-INTLIM-LTCORR-LIB),MDIF-LIB)
;
;       Integration branch:
;
LO:     .FCTR LOOPS-L1-ST-RT-LIB
L1:     .FCTR ANTPTR-BEAMPT-DELO-FRQSEP-RIPROF-TRLOSS-SINT
RT:     .FCTR RGAIN-TGAIN-GPATT
ST:     .FCTR STEPAB-STEPY-STPPAR
;
;       Power and diffraction branch (both access all modules in CL factor):
;
DIF:    .FCTR CL-LIB-(POWER-LIB,(DIFSNR-AVAIL-RT-LIB))
CL:     .FCTR AVTER-CLIMIL-CLIMIX-CLIME-ERFC
;
;       Butterworth filter calculations branch:
;
BUT:    .FCTR BUTFIL-LIB
;
;       MD-918 performance calculations branch:
;
MDT:    .FCTR MDTS-LIB-(M1,M2,M3,M4,M5,M6,M7,M8)
M1:     .FCTR SASEQ-SIGIN-PROUT-LIB
M2:     .FCTR MATCO-LIB-((DINT-SINC-LIB),(CAJI-LIB))
M3:     .FCTR BOTAC-JAMCOM-SINC-LIB
M4:     .FCTR XNOR-LIB-((SINT-LIB),(ERLANG-BERCAL-LIB))
M5:     .FCTR MINV-LIB
M6      .FCTR ORDER-LIB
M7      .FCTR MATOPS-EIGEN-LIB
M8:     .FCTR ELMES-LIB
;
;       AN/TRC-170 performance calculations branch:
;
 NAME   TRCORD
 NAME   TRCXNO
 NAME   TRCELM
 NAME   TRCERL
TR:     .FCTR TRC-ERFC-LIB-(T1,T2,T3,T4,T5)
T1:     .FCTR SASEQ-LIB
T2:     .FCTR TRCERL-ERLANG-LIB
T3      .FCTR TRCORD-ORDER-LIB
T4:     .FCTR TRCELM-ELMES-LIB
T5:     .FCTR TRCXNO-XNOR-LIB
;
 END
```

Figure 3-1 PDP Build Files
Compilation Command File F4PTROPO.CMD

```
F4P TROPO,TROPO=TROPO
F4P DATAINIT,DATAINIT=DATAINIT
F4P ANTGEO,ANTGEO=ANTGEO
F4P ANTPAR,ANTPAR=ANTPAR
F4P ANTPTR,ANTPTR=ANTPTR
F4P ATMOS,ATMOS=ATMOS
F4P AVAIL,AVAIL=AVAIL
F4P AVTER,AVTER=AVTER
F4P BEAMPT,BEAMPT=BEAMPT
F4P BERCAL,BERCAL=BERCAL
F4P BOTAC,BOTAC=BOTAC
F4P BUTFIL,BUTFIL=BUTFIL
F4P CAJI,CAJI=CAJI
F4P CHKDAT,CHKDAT=CHKDAT
F4P CLIME,CLIME=CLIME
F4P CLIMIL,CLIMIL=CLIMIL
F4P CLIMIX,CLIMIX=CLIMIX
F4P DELO,DELO=DELO
F4P DIFSNR,DIFSNR=DIFSNR
F4P DINT,DINT=DINT
F4P EIGEN,EIGEN=EIGEN
F4P ELMES,ELMES=ELMES
F4P ERFC,ERFC=ERFC
F4P ERLANG,ERLANG=ERLANG
F4P ERRIO,ERRIO=ERRIO
F4P ERROR,ERROR=ERROR/CO:7
F4P FROSEP,FROSEP=FROSEP
F4P GPATT,GPATT=GPATT
F4P HORANG,HORANG=HORANG
F4P INDATA,INDATA=INDATA
F4P INTLIM,INTLIM=INTLIM
F4P JAMCOM,JAMCOM=JAMCOM
F4P LOOPS,LOOPS=LOOPS
F4P LTCORR,LTCORR=LTCORR
F4P MATCO,MATCO=MATCO
F4P MATOPS,MATOPS=MATOPS
F4P MDIF,MDIF=MDIF
F4P MDTS,MDTS=MDTS
F4P MINV,MINV=MINV
F4P ORDER,ORDER=ORDER
F4P OUTDAT,OUTDAT=OUTDAT
F4P POWER,POWER=POWER
F4P PROUT,PROUT=PROUT
F4P RGAIN,RGAIN=RGAIN
F4P RIPROF,RIPROF=RIPROF
F4P SASEQ,SASEQ=SASEQ
F4P SIGIN,SIGIN=SIGIN
F4P SIM,SIM=SIM
F4P SINC,SINC=SINC
F4P SINT,SINT=SINT
F4P STEPAB,STEPAB=STEPAB
F4P STEPY,STEPY=STEPY
F4P STPPAR,STPPAR=STPPAR
F4P SUBID,SUBID=SUBID
F4P SUMPAG,SUMPAG=SUMPAG
F4P TGAIN,TGAIN=TGAIN
F4P TRANSF,TRANSF=TRANSF
F4P TRC,TRC=TRC
F4P TRLOSS,TRLOSS=TRLOSS
F4P UNITCV,UNITCV=UNITCV
F4P UNITS,UNITS=UNITS
F4P XNOR,XNOR=XNOR
```

```
>TKB @TKBTROPO
```

The overlay file links explicitly to the FORTRAN IV-PLUS object time system library, F4POTS.OLB. This reference is not necessary if F4P is the system default since the correct Fortran modules would be included in SYSLIB.OLB. Contents of these files appear in Figures 3-1 through 3-3.

3.1.2 ITEL AS-5, IBM System/360, and IBM System/370 Version

The IBM version consists of a single tape file, containing TROPO in IBM OS FORTRAN IV (H Extended) source code followed by one sample input data file which is a concatenation of four separate input files.

Compiling and linking are system-dependent and should be straight-forward since all of the source lines are contained in a single file. (After reading the tape file onto disk, it is necessary to edit out the sample data file before compiling.) This version is not separated into modules since an overlay structure is not needed for the ITEL or IBM computers.

This file was written out to tape with a blocksize of 16000 bytes, where each block holds 200 80-character fixed-length records. Since the tape contains only source lines padded out with blanks to 80 bytes and no utility overhead characters or file headers, this version is very general and can be installed on ANY computer which can do direct tape reads of ASCII characters with odd parity at a density of 800 b.p.i. In addition, the IBM Fortran language of the source code is very close to ANSI standard Fortran. The major Fortran differences between the PDP and IBM versions are listed in Section 3.1.3.

The following sections should provide all necessary instructions to ensure successful program execution, given the availability of expert help on the configuration of your computer system.

3.1.1 PDP-11/70 Version

The PDP version of TROPO is available on 9-track magnetic tape as a set of FORTRAN IV-PLUS source files, simple command files and a sample input file (a concatenation of four separate input files), all of which were copied from disk to tape at a density of 800 b.p.i. by the DEC utility program called FILEX (FLX).

The command line for the reverse transfer of all files from tape to the user's disk is:

```
>FLX /RS=MMn:[*,*]*.*/DO
```

where n is the integer identifying the tape drive.

This command is exact for the RSX-11M operating system and for a PDP-11/70 whose tape drive bears the device name of MMn:. Though FLX is included in DEC operating systems other than RSX, there may be small syntactic differences, especially in the device name, which will have to be made to this line.

Compilation of the FORTRAN-IV PLUS modules may be accomplished under RSX by entering the commands on line or by executing the command file F4PTROPO.CMD supplied on the tape:

```
>@F4PTROPO
```

When compilation is successful, build the task with the command file TKBTROPO.CMD, which in turn references the overlay file TROPO.ODL, both of which are also on the tape:

SECTION 3
USE OF THE TROPO COMPUTER PROGRAM

This section provides the information needed to run a link evaluation using TROPO. It consists of four basic items:

1. How to set up the TROPO program on your system;
2. How to prepare a TROPO input file;
3. How to initiate a TROPO run on your system;
4. How to interpret the output of TROPO.

3.1 OVERVIEW

First of all, you will need to have a copy of the executable TROPO program available on your system. TROPO has been delivered* available in Fortran source code on industry-standard 9-track magnetic tape. Two versions have been delivered, one for PDP-11/70 and one for the IBM System/370 or Itel AS-5 or equivalent systems. The difference between the versions with respect to both the tape formats and Fortran language details are discussed in Sections 3.1.1 through 3.1.3. The source code will have to be transferred from tape to disk and then compiled and linked to form an executable memory-image program. Next, for each run an ASCII (EBCDIC for IBM version) input file needs to be set up in the specific form detailed in Section 3.2 containing the link parameters of interest to you. Finally, it will be necessary to supply certain system-dependent commands either on-line or from a "command file" on the disk to execute TROPO. In older card-oriented batch systems, execute TROPO by means of control cards forming a "sandwich" around the deck containing your input data.

---

* Delivered to the Defense Communications Engineering Center under Contract DCA100-80-C-0030.

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SECTION 2
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ICLIME	Climate class indicator; Default = 0. 0 = NBS TN-101 climate 1 = MIL-HDBK-417 climate 2 = New user-supplied climate
CLIMAT	Climate specification code or description. If ICLIME = 0 or 1, CLIMAT must be one of the following codes:

NBS TN-101 codes

- CL = Continental Temperate (All Year)
- MTL = Maritime Temperate Overland
- MTS = Maritime Temperate Oversea
- MSL = Maritime Subtropical Overland
- CT2 = Continental Temperate - Time block II
- DS = Desert, Sahara
- EQU = Equatorial
- CS = Continental Subtropical

MIL-HDBK-417 codes:

- CT = Continental temperate
- MTL = Maritime Temperate Overland
- MTS = Maritime Temperate Oversea
- MS = Maritime Subtropical
- DS = Desert, Sahara
- EQU = Equatorial
- CS = Continental Subtropical
- MED = Mediterranean
- POL = Polar

If ICLIME = 2, CLIMAT may be any descriptive title, up to 4 characters, left-justified.

NOTE: For MIL-HDBK-417 climates, Continental Temperate data is used for the Polar climate zone (POL), and the average of Maritime Subtropical and Maritime Temperate Overland data is used for the Mediterranean zone (MED), as recommended in MIL-HDBK-417.

GPF
YMIN,DEMIN
YZERO,Y900

These input parameters are used only for ICLIME = 2. They represent the three data points needed for the program to compute the equation for the $Y_0(90)$ curve fit and are defined as follows:

GPF = frequency correction factor. (DEFAULT=1). A number other than unity should be entered when the YMIN and Y900 variability data are for a frequency other than the frequency of interest (see Figure 10.15 in NBS TN-101, Jan. 1967, Vol. 1).

YMIN,DEMIN = The absolute value of $Y_0(90)$ and d_e at the minima of the curve. DEMIN is in km. YMIN may be entered as a positive or negative number. Program assumes YMIN is negative.

YZERO = The value of $Y_0(90)$ at $d_e = 0$.
Default = 0.

Y900 = The value of $Y_0(90)$ for $d_e > 900$ km. Must be entered with proper sign.

If ICLIME is not entered as 2, these values are not read in.

DISTU — Distance units specification, A4 format, left justified: smi, km, or nmi. All parameters designated below as having units in smi/nmi/km will be interpreted according to the setting of DISTU, as follows:

SMI	Statute Miles
NMI	Nautical Miles
KM	Kilometers

HDU — Height and diameter units specification A4 format, left justified: FT or M, standing for feet or meters, respectively. All parameters designated below as being in units of ft/m will be interpreted according to the setting of HDU.

NOTE: DISTU and HDU must both be either English or metric units. If these are mixed upon input, TROPO outputs an error message and stops.

ANGU — Angle units specification, A4 format, left justified: DEG or MRAD. All parameters representing angles will be interpreted according to the setting of ANGU, as follows:

DEG	all angles are in degrees
MRAD	all angles are in milliradians, i.e., 1000 mrad = 1 radian.

FREQU — Frequency units specification, A4 format, left justified: MHz or GHz. All frequency units will be interpreted according to the setting of FREQU, unless otherwise noted.

POWERU — Transmit power units specification, A4 format, left justified: W (for Watts) or dBm.

TXPOW — Transmit power in units specified by POWERU. Default is 70 dBm and 10000 W.

F — Frequency (GHz, MHz depending on value of FREQU entered previously). The reference path value loss calculations are accurate for frequencies between 100 MHz and 35 GHz. The path loss distribution calculations are valid for frequencies between 100 MHz (NBS climates) or 250 MHz (MIL-HDBK 417 climates) and 10 GHz. The upper frequency limit is due to the lack of modeling of rain attenuation and scattering effects.

SP — Service probability. Default = 0.95.

NFIG — Noise figure in dB. Default = 4.0 dB.

TLL — Transmitter line loss in dB. Default = 0 dB.

RLL — Receiver line loss in dB. Default = 0 dB.

General Path Geometry Parameters:

For all cases (both troposcatter and mixed tropo/diffraction cases), the following data is required.

D — Great circle distance (measured at sea level) between transmitter and receiver (km, smi, nmi). If the path length is greater than 500 km, the atmospheric absorption loss calculation will overestimate the actual loss.

HTO,HRO	Elevation of transmit and receive sites above sea level (meters or feet).
HT, HR	Nominal height of transmit and receive antennas above site ground (feet or meters). Note: In the case of multiple antennas, the nominal height is the arithmetic mean of the heights from the center of the various antennas to the ground.
PTYPE	Path type indicator

0 = Troposcatter (power vs. delay profiles included in output)

1 = Combination troposcatter and diffraction (power vs. delay profiles included in output)*

10 = Troposcatter (power vs. delay profiles are omitted from summary output)

11 = Combination troposcatter and diffraction (with power vs. delay profiles omitted from summary output).

* NOTE: Even if the user is certain that only the diffraction component is significant, the program will compute the troposcatter loss to make sure that is the case. Also, the user need not make a distinction between single, double or triple diffraction at this point. The program will determine this from the terrain data entered later.

When PTYPE = 0 or 10 (troposcatter calculations only); enter the following data:

TROPOSCATTER-ONLY SECTION

NOTE: The following parameters are used to calculate the reference troposcatter path loss (see Section 2.5.2 for details).

ITOFF — Control indicator for entry or calculation of transmit/receive radio horizon angles THET, THER. Use as follows:

- 0 = user specifies radio horizon elevation angles THET, THER.
- 2 = radio horizon elevation angles THET, THER are calculated in program.

THET, THER — Radio horizon elevation angles at transmit and receive sites in degrees or mrad. If ITOFF=2, they are ignored, i.e., the program recalculates THET and THER from the terrain data specified below.

DLT, DLR — Distance to radio horizon from transmitter and receiver respectively (km, smi, nmi). If ITOFF=0, they are ignored. If ITOFF=2, DLT and DLR must be greater than zero.

HLT, HLR — Transmit and receive radio horizon elevation above sea level (meters or feet). If ITOFF=0, they are ignored. If ITOFF=2, they must also be specified.

NOTE: The following parameters are used to calculate median correction factors and path loss variability for the specified climate zone.

NTERR — Control indicator for entry or calculation of effective transmitter and receiver height HTE, HRE above average terrain elevation. Use as follows:

0 = user will supply HTE and HRE directly

1 = user will input average terrain elevation (above sea level) between transmitter and its radio horizon as AVETX and between receiver and its radio horizon as AVERX.

2 = user will input NP1 evenly-spaced terrain elevations (above sea level) between transmitter and its radio horizon which are stored as HI(1) through HI(NP1). User will also input NP2 evenly-spaced terrain elevations between receiver and its radio horizon which are stored as HI(NP1+1) through HI(NP1+NP2). The spacing between NP1 terrain elevation data does not have to equal the spacing for NP2 data. Also NP1 does not have to equal NP2.

NOTE: If ITOFF = 0, then NTERR must either be 0 or 1.

HTE, HRE	Effective transmit/receive antenna height above average terrain elevation (meters or feet). Used only when NTERR = 0, otherwise ignored. See Section 2.5.4.7 for definition of effective antenna height above average terrain elevation.
AVETX,AVERX	Average terrain elevations (above sea level) between transmitter and its radio horizon, and between receiver and its radio horizon (meters or feet). Used only when NTERR = 1, otherwise ignored.
NP1, NP2	Number of terrain data points for calculation of effective transmit and receive antenna height, respectively. When NTERR = 2, NP1 and NP2 must <u>each</u> be greater than 5 but less than 31. If NTERR = 0, 1, set NP1 = 1, NP2 = 0. NOTE: NP1 need not equal NP2.
HI(1:NP1+NP2)	Array of NP1 evenly spaced terrain elevations (above sea level) between transmitter and its radio horizon followed by NP2 evenly-spaced terrain elevations between receiver and its radio horizon. The spacing between the NP1 terrain elevation data does not have to equal the spacing between the NP2 terrain elevation data. All NP1 and NP2 terrain elevation data can be specified in one line or in more than two lines in the input file.

HI(1) = terrain elevation at transmit site = HT0

HI(NP1) = terrain elevation at transmit radio horizon = HLT

HI(NP1+1) = terrain elevation at receive radio horizon = HLR

HI(NP1+NP2) = terrain elevation at receive site = HR0.

When NTERR = 0, 1 enter only one arbitrary value which is ignored.

When PTYPE = 1 or 11 (mixed troposcatter-diffraction calculations) enter following data:

(NOTE: The MD-918 modem performance can be calculated for mixed troposcatter/diffraction paths as long as the product of the delay spread of the scatter component and the data rate is less than 0.2. Modem performance calculations for pure diffraction paths for which the delay spread of the scatter path is too small are not allowed (an error message is printed).)

DIFFRACTION SECTION

NOTE: The following parameters are used to calculate the reference troposcatter and diffraction path loss.

NOBS — Number of diffraction obstacles up to a maximum of three (3).

HL(1:NOBS) — Array containing elevation of diffraction obstacles above sea level in meters or feet. Note: HL(1) is elevation of transmitter radio horizon HLT while HL(NOBS) is elevation of receiver radio horizon HLR.

DL(1:NOBS) Array containing great circle distances of diffraction obstacles from transmitter in km, nmi, or smi.

DS(1:NOBS) Array containing the "effective horizontal extent" of the obstacles along the great circle path (in km, nmi, smi). If an obstacle is considered to be a knife-edge then its corresponding value of DS is zero. Otherwise DS represents the distance between the points at which the diffraction ray path is tangent to the obstacle. When DS is not zero, the distance DL from transmitter to obstacle is measured to the mid-point between the points of tangency. Thus note that the transmitter radio horizon distance is given by DLT=DL(1)-DS(1)/2, while the receiver radio horizon distance is given by DLR=D-DL(NOBS)+DS(NOBS)/2.

NOTE: The following parameters are used to calculate median correction factors and path loss variability for the specified climate zone.

NTERR Control indicator for entry or calculation of effective transmitter/receiver antenna height HTE, HRE above average terrain elevation and effective obstacle height HLEF(1:NOBS) above average terrain elevation. Use as follows:

0 = user will supply HTE, HRE and HLEF(1:NOBS) directly in feet or meters

1 = user will input average terrain elevation (above sea level) at transmit site as AVETX, at receive site as AVERX, and at each diffraction point as HLAV(1:NOBS)

2 = user will input NPM(1)=NP1 evenly spaced terrain elevations (above sea level) between transmitter and 1st diffraction point, NPM(2)=NP2 evenly spaced terrain elevations between 1st diffraction point and second diffraction point (or receiver if single diffraction), ..., NPM(NOBS+1)=NPN evenly spaced terrain elevations between the last diffraction point and the receiver.

HTE, HRE — Effective transmitter/receiver antenna heights above average terrain elevation in feet or meters. Used only when NTERR=0; otherwise ignored. See Section 2.5.4 for definition.

HLEF(1:NOBS) — Array of effective diffraction obstacle heights above average terrain elevation in feet or meters. Used only when NTERR=0; otherwise ignored.

AVETX, AVERX — Average terrain elevation above sea level at transmit and receive sites, respectively (feet or meters). Used only when NTERR=1; otherwise ignored.

HLAV(1:NOBS) Array of average terrain elevation above sea level at each diffraction point (feet or meters). Used only when NTERR=1; otherwise ignored.

NPM(1:NOBS+1) Array containing number of terrain elevation data points (NP1, NP2, ..., NPN) to be used for calculation of average terrain elevation between transmitter and 1st diffraction obstacle (NP1), first and second diffraction obstacle (NP2), ..., last diffraction obstacle and receiver (NPN). Note that NPN=NPM(N=NOBS+1). Note also that NP1, NP2, ..., NPN need not be equal. When NTERR=2, NP1, NP2, ..., NPN should each if possible be greater than 5 but must be less than 31. If NTERR=0 or 1, set NP1=1, NP2=NP3= ...= NPN=0.

HI(1:NP1+NP2+ ... + NPN) Array containing NP1 evenly spaced terrain elevation data points between transmitter and 1st diffraction point, followed by NP2 evenly spaced terrain elevation data points between 1st and second diffraction points, etc., followed by NPN evenly spaced terrain elevation data points between last diffraction point and receiver. Note that the spacing between the first NP1 terrain data need not equal the spacing between the next NP2 terrain data, etc. When NTERR=2, the terrain data points should be selected such that

HI(1) = terrain elevation (above sea level) at transmit site = HT0

HI(NP1) = HI(NP1+1) = terrain elevation at first diffraction point = HL(1)=HLT

HI(NP1+NP2) = HI(NP1+NP2+1) = terrain elevation at last diffraction point = HL(NOBS) = HLR

HI(NP1+...+NPN) = terrain elevation at receive site = HR0.

When NTERR=0,1 enter an arbitrary value which is ignored.

ersity Configuration Parameters:

ERSITY DATA INPUT SECTION

The next line of input is a switch (DIVTYP) specifying the ersity configuration to be modeled. Most standard tropo syss can be modeled by DIVTYP=0, 1, or 2. DIVTYP=4 permits nonndard multi-antenna space diversity systems to be modeled by ing an optional group of parameters at the end of the file, t prior to the END line. If this latter option is selected VTYP=4), the parameters immediately following DIVTYP (specifily, TDIAM through RSEP) are ignored and the more detailed data ered at the end of the file is used instead. The standard ersity parameters are interpreted as follows:

DIVTYP Switch controlling the type of diversity system modeled as follows:

0 = Performance for all combinations of space, angle, and frequency diversity is calculated. More specifically 2S, 2S/2F, 2S/2A and 2S/2A/2F diversity configurations are modeled.

1 = Performance for all combinations of angle and frequency diversity is calculated. More specifically, 2A, 2F and 2F/2A diversity configurations are modeled.

2 = Space/polarization/angle diversity configurations 2S/2P and 2S/2P/2A are modeled.

3 = Reserved for future program enhancements.

4 = Experimental diversity configuration. When this mode is used, the data items from TDIAM through MODSIG are ignored but must be present. Instead, the program uses the data for non-standard diversity systems, which must be inserted between MODSIG and the END line. In this mode, modem performance is not calculated. The output contains only propagation data.

TDIAM Transmit antenna aperture diameter in feet or meters. All transmit antennas assumed identical.

RDIAM Receiver antenna aperture diameter, in feet or meters. All receiver antennas assumed identical.

0 = no calculation

1 = power calculation if I1 = I2 and correlation calculation if I1 ≠ I2.

2 = Power per unit delay and total power calculation if I1 = I2. Correlation on unit delay and total correlation calculation if I1 ≠ I? I1 and I2 indicate the pairs of cha... .s to be considered. The range of the indices I1, I2 is 1 ≤ I1 ≤ NR and (for each I1) I1 ≤ I2 ≤ NR.

UTH(NT)
UTV(NT)
UTL(NT)

Horizontal, vertical and longitudinal location of transmitting antenna i_T relative to the nominal position at transmit local site i_T = 1, ..., NT (ft/m). Note: the nominal antenna position is (0, HT, 0).

URH(NR)
URV(NR)
URL(NR)

Horizontal, vertical and longitudinal location of receiving antenna IR relative to the nominal position at receive local site i_R = 1, ..., NR (ft/m). Note: the nominal antenna position is (0, HR, 0).

NOTE: For these coordinates, the longitudinal axis is taken to be along the great circle plane containing the transmit and receive sites. The positive longitudinal direction is from the transmitter to the receiver site. Up is positive in the vertical direction and left is positive in the horizontal direction, as seen looking from transmitter to receiver.

(NR) Receiver antenna diameters (ft/m).

[TEO(NT) Antenna boresight elevation above the horizon, i.e., it is the angle at which each transmit antenna is aimed relative to the horizon (deg/mrad).

[REO(NR) Antenna boresight elevation above the horizon, i.e., it is the angle at which each receive antenna is aimed relative to the horizon (deg/mrad).

[TAO(NT) Transmit antenna boresight azimuth, relative to the great circle plane containing the receive and transmit sites. Positive counter-clockwise (deg/mrad).

[RAO(NR) Receive antenna boresight azimuth relative to the great circle plane containing receive and transmit sites. Positive clockwise (deg/mrad).

)LT(NT) Transmit antenna polarizations. The integer values 0 and 1 represent any two orthogonal polarizations. These may, for example, represent horizontal and vertical polarization.

)LR(NR) Receive antenna polarizations. Same as IPOLT.

R(I1,I2) Channel complex-envelope correlation and cross-correlation calculation indicator array. The values in IBR for each pair of receive ports I1 and I2 are interpreted as follows:

XANG,ELANG — Interferer azimuth and elevation (above horizon) angle of arrival arrays of size MANG respectively. Default = 0.,0. These arrays are input as pairs: (XANG(I), ELANG(I), I=1, MANG) (deg/mrad).

MODSIG — Interference signal modulation format indicator. Default = 1.

0 = analog FDM/FM
1 = digital QPSK

on-Standard Diversity Cases:

SER SUPPLIED DIVERSITY INPUT

If DIVTYP = 4 was specified above, the program ignores the tandard diversity parameters immediately following DIVTYP (which ust nevertheless be present in the file) and instead uses the ollowing data, which must be inserted prior to the END line in his case. Note: Propagation calculations only are performed or DIVTYP = 4, in the present version or troposoftware.

NT — Number of transmit antennas.

NR — Number of receive antenna ports. Note: An antenna with angle diversity feeds has two receive ports. Similarly an antenna with cross-polarized feeds has two receive ports. Hence NR is the number of receive antennas multiplied by the number of feeds per antenna.

AT(NT) — Transmit antenna diameters (ft/m).

rate since two QPSK symbols are transmitted in one signaling period. This is referred to as the TRC-170 modem. Default value = 1.

:ERFERENCE PARAMETER INPUT SECTION

JPOW	Interference power density, i.e., interference power in a 1 Hz bandwidth in dBm/Hz. To indicate no interference, set JPOW < -174 dBm, the background noise level, or use the default, which is -1000 for no interference. For JPOW < -174 (no interference) all parameters following JPOW are ignored (not used) by the program, except for the END marker.
JBW	Interference signal bandwidth in MHz. Default = desired signal bandwidth BW.
FJSEP	Frequency separation between the interference signal and the desired signal in MHz. For co-channel interference enter FJSEP = 0. For adjacent channel interference FJSEP must be greater than the larger of BW (desired signal bandwidth) or JBW (interfering signal bandwidth). Default = larger of BW or JBW.
MANG	Number of interferer azimuth and elevation angle of arrival pairs for which interference calculations are to be done. Default = 1.

program assumes that the past intersymbol-interference due to the past 3 symbols is cancelled by the backward equalizer in the MD-918 modem.

AN/TRC-170/DAR MODEM PARAMETER SECTION

NOTE: The following parameter is used only if MODPAT = 2 is specified. The AN/TRC-170 modem calculations are allowed for any combination of data rates and bandwidths provided the data rate does not exceed the bandwidth or fall below one-fourth of the bandwidth.

TRCTYP — A parameter which indicates whether the AN/TRC-170 or DAR modem employs a single frequency or two frequencies to transmit information over the signaling period T_0.

= 0 If one QPSK information symbol is transmitted at one frequency in the time interval $(0, T_0/2)$. The QPSK symbol rate is $1/T$ and is equal to the signaling rate $1/T_0$. This is referred to as the DAR modem.

= 1 If one QPSK information symbol is transmitted at one frequency in the time interval $(0, T_0/2)$ and a second QPSK information symbol is transmitted at another frequency in the time interval $(T_0/2, T_0)$. In this case the QPSK symbol rate is still $1/T$ but the signaling rate $1/T_0$ is half the symbol

NERT Bit error rate threshold indicator for yearly fade outage probability calculation. Default = 2.

0 = All three thresholds: 10^{-3}, 10^{-4}, 10^{-5}.*

1 = 10^{-3} only

2 = 10^{-4} only

3 = 10^{-5} only.

D-918 MODEM PARAMETER SECTION

NOTE: The following parameters are used only if MODPAT = 1 is specified. The MD-918 modem calculations are allowed for any combination of data rates and bandwidths provided the data rate does not exceed twice the bandwidth or fall below 1/30 of the bandwidth.

TAPW MD-918 adaptive-forward equalizer (AFE) normalized tap spacing. Default = 0.5. Tap spacing in sec = 2*TAPW/DRATE. Other normalized tap spacings that may be of interest are 1., 0.25 or 0.75.

LISI Number of future intersymbol-interference (ISI) contributors considered. Default = 2. The

---

Only one BER threshold can be used for mixed mode troposcatter/diffraction propagation paths. (I.e., for PTYPE = 1, NERT may only equal 1,2, or 3.)

sum of the mission bit rate plus service (orderwire) channel bit rate and any overhead factors for multiplexing of the mission bit streams and orderwire channels if any. The data rate must always be less than twice the bandwidth (less than 2 bits/sec/Hz) for the MD-918 and less than the bandwidth (1 bit/sec/Hz) for the AN/TRC-170. It must also be greater than 1/30 of the bandwidth for the MD-918 and greater than 1/4 of the bandwidth for the AN/TRC-170. If the data rate is not within the allowable ranges, TROPO prints an error message and stops. For the MD-918 modem, when the data rate is less than half the bandwidth, but greater than a thirtieth of the bandwidth, the program assumes that multiple chips per bit are transmitted to exploit the implicit diversity available over the larger available bandwidth. This is similar to modulating the information sequence by a PN sequence. The PN sequence which modulates each bit is calculated by the program and printed. If the user does not wish to make use of this feature he must specify a data rate which is greater than half the bandwidth or conversly specify a bandwidth which is no greater than two times the data rate. In practice the current MD-918 modem does not use a PN sequence to exploit implicit diversity as does the AN/TRC-170 and DAR modems at low bit rates. The current version of the program does not model the low rate performance of the AN/TRC-170 or DAR modems.

IFILRX	Receiver filter type specification
	0 = MD-918 receiver filters, i.e., cascade of Butterworth filter with rectangular impulse response filter of duration equal to QPSK symbol duration.
	1 = (not allowed)
	2 = TRC-170 receiver filter, i.e., Butterworth filter.
FCTX	3-dB cut-off frequency of transmitter filter, (i.e., half of 3-dB bandwidth) in Hz. (Note: filter is Butterworth lowpass type.)
FCRX	Similar to FCTX but pertains to receiver filter.
NPOLTX	Number of poles (Butterworth lowpass) of the transmitter filter.
NPOLRX	Similar to NPOLTX but pertains to receive filter.
BW	Bandwidth (MHz). Default = 7.0. Note that this parameter is always interpreted in MHz, regardless of the setting of FREQU.
DRATE	Data rate (bits/sec). Default = 6.6×10^6.
NOTE:	The data rate is defined as the total information rate transmitted by the modem, i.e., the

4-pole Butterworth filter with 3-dB cut-off frequency f_c equal to 0.5 BW. Since the 3-dB bandwidth of the filter is twice the cut-off frequency then the 3-dB bandwidth of the receiver filter is equal to the specified bandwidth. When adjacent channel interference calculations are desired, the receiver filter 3-dB cut-off frequency is calculated so that the SNR degradation due to the interference does not exceed 1 dB.

When IBW = 3 the filter parameters IFILTX, IFILRX, FCTX, FCRX, NPOLTX and NPOLRX must be specified by the user. These parameters are ignored (i.e., not used) otherwise.

IFILTX Transmit filter type specifications

0 = MD-918 transmitter filters, i.e., cascade of Butterworth filter with rectangular impulse response filter of duration equal to QPSK symbol duration.

1 = TRC-170 transmitter filters, i.e., cascade of Butterworth filter with rectangular impulse response filter of duration equal to half of symbol duration.

2 = (not allowed)

CN2(KPROF) KPROF values of CN2; the atmospheric structure constant as a function of height in $m^{-2/3}$.

Modem Parameters:

MODEM INPUT SECTION

NOTE: The following parameters apply to all modem types. The type of modem whose performance is predicted is selected by setting MODPAT (second data parameter in input file) to the proper value.

IBW Switch indicating type of RF bandwidth constraint to be used on desired signal, as follows:

0 = No constraint; no RF filter used at transmitter and receiver.

1 = Transmitter filter chosen by program to meet 99% power bandwidth constraint.

2 = Transmitter filter chosen by program to meet FCC Docket #19311 bandwidth constraint.

3 = User specifies both transmitter and receiver filters by means of additional parameters described below.

NOTE: For IBW = 1 or 2, the bandwidth of the transmitter filter is determined by the value entered for BW, below. The receiver filter is a

NOTE: The following parameters should only be specified when the troposcatter loss for the specified structure constant profile CN2(1) ... CN2(KPROF) is desired. However, when these parameters are specified, the median correction factors and path loss distribution about the median should be disregarded unless the structure constant height profile happens to correspond to winter afternoon conditions in continental temperate climates. If the user desires a path loss distribution for a specific climate in order to obtain modem performance predictions, enter KPROF = 0. (See Section 2.5.2 for further information on CN2).

TAPOUT	Enter T (TRUE) to have simulator tap values output in FOR002.DAT (Default). Enter F (FALSE) to suppress the calculations and output.
SPE	Simulator tap spacing in nanoseconds (Default = 67).
MLAST	Number of simulator taps (Default = 16).
KPROF	Number of samples of CN2 to be entered (see below) up to 50.
HLOW	Lowest height above sea level at which CN2 is specified in feet or meters.
DELH	Spacing of samples of CN2 (see below) in feet or meters. Lowest height HLOW and the sample spacing DELH should be chosen so that the CN2 profile within the common volume is completely specified.

radius factor ERFAC is calculated by TROPO when SEAN > 0 is specified. (See Section 2.5.2 for details). If SEAN is not known, the user must enter SEAN = 0. The program will then use the value of ERFAC supplied by the user or the default value ERFAC = 1.33.

ERFAC — Yearly median value of effective earth radius factor K. Default = 1.33. Used only when SEAN=0; otherwise the program will calculate the correct value corresponding to the specified SEAN.

SCPARM — Wavenumber spectrum slope parameter M for atmoshperic turbulence. Default = 3.66. For frequencies less than 1.0 GHz SCPARM is reset to 5.0. For frequencies above 5 GHz, the recommended value is 3.66. At frequencies between 1 and 5 GHz a value of 3.66 will yield a conservative value for the path loss. A value of 5 should be used to get predictions which are in close agreement with NBS TN 101.

NACCU — Accuracy parameter used in the common volume integration. Default = 40. See description in Section 2.5.2 (A).

ERR — Common volume integration resolution parameter. Default = 0.001. Values smaller than 0.025 should be specified.

TFLAG Parameter which indicates whether transmitting antennas (if more than one) are spaced vertically or horizontally; TFLAG = 0 if horizontally spaced, = 1 if vertically spaced. TFLAG must be zero for this version of TROPO. Otherwise an error message is printed out, i.e., only horizontal spacing is presently allowed.

TSEP Center-to-center spacing between transmitting antennas. If DIVTYP=0 or 1, TSEP=0. If DIVTYP=2 TSEP must be greater than antenna diameter.

NOTE: The spacing of transmit site antennas does not enter into the calculation of diversity correlation for 2S and 2S/2F configurations. However it does impact the calculations for 2S/2P diversity.

RFLAG Same as TFLAG except that it applies to the receiving antennas.

RSEP Center-to-center spacing between receiving antennas. If DIVTYP = 1, RSEP = 0, otherwise it must be greater than antenna diameter. The spacing between receiving antennas for frequency or angle diversity configurations does not enter into the calculations.

<u>Propagation and Integration Control Parameters:</u>

PROPAGATION DATA INPUT SECTION

SEAN <u>Minimum</u> monthly median value of refractivity at sea level. Typical values are between 290 and 390 depending on climate zone. See Figure 2-3 for a world map of SEAN. The effective earth

TELH — Transmit antenna beam boresight elevation above the radio horizon elevation THET (degrees/mrad).

NOTE: TELH=0 implies that the antenna is pointing at the horizon. Typically antennas are aimed from a quarter-beamwidth to a beamwidth above the horizon THET. If the user does not know how high above the horizon the antenna is pointing, he should enter a value of TELH equal to or grater than 4000. Then the program will set the antenna boresight elevation to a quarter beamwidth above the horizon if F<1GHz or half-beamwidth if F > 5 GHz. At frequencies between 1 and 5 GHz a proportional value between a quarter and a half beamwidth is assumed by the program.

RELH — Receive antenna main beam boresight elevation above radio horizon elevation THER. All receive antennas assumed the same. If not known enter a value equal or greater than 4000. The values entered (or calculated) for TELH and RELH are used to determine the scattering angle and hence the troposcatter reference path loss.

PHDIV — Squint angle between upper and lower receiver angle diversity beams (deg/mrad). DEFAULT= beamwidth. If a value of zero is entered, the default value is assumed by program.

END — String denoting the end of the input parameters. Upon reading 'END' TROPO will execute and output its results. If another input data file is appended to the first, TROPO will read 'START' again and process that data independently of the first. Thus, any number of input data files can be concatenated and processed to produce one output data file.

3.3 EXECUTION OF TROPO PROGRAM

Once you have successfully compiled and linked TROPO to obtain an executable version of the program (see Section 3.1) and have prepared one or more input files in the proper format (Section 3.2), you are ready to make a run with TROPO. The instructions for doing this are given below for PDP-11/70 and IBM 370 (Itel AS/5) systems.

3.3.1 PDP-11/70 Under RSX-11M

First, log in with a valid user code on the system. Next, select an input file for the run and copy it into TROPO.DAT. This is done by means of the command

```
PIP TROPO.DAT = filename <CR> (<CR> = Carriage Return)
```

where "filename" is the name of the selected input file or the names of a number of files. If it is not in your user directory, the user code of the directory where it is to be found must be included in square brackets before "filename".

Now run TROPO by entering the command RUN TROPO <CR>. Again, if TROPO.TSK resides in another user's directory, you must type that user's UIC in square brackets before the name TROPO.

3.4 INTERPRETING THE OUTPUT

In this section, we summarize the output produced by TROPO during a typical run. The reader is referred to Section 4 for examples of actual TROPO output, which will help clarify the descriptions giver here. A list of the output variables similar to that for the input variables is given in teh Software Documentation Report.

TROPO produces up to three output files as follows:

3.4.1 Digital Propagation/Modem Output File

This file is on unit LOUT and may be assigned to a disk or user terminal depending upon LOUT's value in the source code and your system conventions. For example, in the PDP-11/70 version, using a value of LOUT equal to 2 would cause the default Fortran file named FOR002.DAT to be opened as the output file; if LOUT were equal to 5 the output would be written to the user's terminal.

This file begins with a summary of the input parameters TROPO has obtained from the input file. These have been explained in detail in Section 3.2. Some conversions have been performed, but these should be self-explanatory. For example, even though transmitter power may have been entered in dBm, the input summary will show the corresponding value in Watts as well. Similarly, for DIVTYP = 0, 1, and 2, the inputs pertaining to the various transmit and receive ports are printed for each port, even though only a single value was entered. Note that the number of receive ports is equal to the number of receiving apertures multiplied by the number of feeds per aperture. The number of ports is specified by the value selected for DIVTYP as discussed in Section 2.5.6.

The input parameters are grouped into Path Parameters and Modem Parameters. The latter group includes the characterization of the interference environment (if any).

Following the input parameters, the propagation output parameters are printed. If diffraction is modeled, both troposcatter and diffraction outputs are displayed.

The troposcatter propagation parameters printed out are the reference troposcatter path loss for the lower and upper angle diversity beams, i.e., the program assumes that each receive antenna has angle diversity feeds. However the parameters for the elevated beam are used only to compute the performance of diversity configurations involving angle diversity. The rms (2-sigma) delay spread of the signals received on the lower and upper beams are also printed out as is the average delay of the troposcatter signal in the upper and lower beams relative to a reference defined in Section 2.6.3. The yearly distribution of the troposcatter path loss is printed next. The yearly median of the path loss is equal to the reference path loss plus a climate correction factor, VDE, which depends on an effective distance parameter, DE. The variability about the median Y_0 (QT,DE) in dB is also climate zone and effective distance dependent. For a more detailed description of the definition of the reference path loss, median correction factor and variability about the median, the reader is referred to Section 2.5 of this document.

From the troposcatter path loss distribution TROPO calculates the yearly distribution of the received signal level (RSL) and the yearly distribution of the short-term mean signal-to-noise ratio per bit, E_b/N_0, for the specified service probability. The service probability parameter is a measure of the desired accuracy of the prediction and can be interpreted as the percentage of cases for which the predicted median RSL (or E_b/N_0) will exceed the actual measured median RSL. It is for this reason that the path loss distribution printed out next to the RSL and E_b/N_0 distributions will differ from the path loss distribution inferred from the values printed out for the reference path loss, median correlation factor and variability about the

median. The two distributions will be identical only when the service probability is 0.5, i.e., when there is only a 50% probability of predicting a median RSL (or E_b/N_0) which exceeds the measured median. For a detailed explanation of how service probability is used to calculate the distribution of the RSL and E_b/N_0, the reader is referred to the final report.

If mixed troposcatter-diffraction is specified, the program calculates the long term distributions (including service probability) of the troposcatter and diffraction components of the received signal separately. The distributions of RSL and E_b/N_0 for the troposcatter component are printed out first followed by the corresponding distributions for the diffraction component. For a more detailed description of the distribution of the diffraction component path loss, the reader is referred to Section 2.6 of this document. In addition to the distributions TROPO also calculates and prints out the relative delay between the diffraction component and the mean delay of the troposcatter component.

If MODPAT is not zero, the results of the modem performance analysis and RF filter parameters are then printed. If IBW = 1 or 2, the program calculates the number of poles and 3-dB cut-off frequency (half of 3-dB bandwidth) of the transmitter RF filter required to meet the bandwidth constraint. The program assumes that the transmitter RF filter and receiver IF filter are Butterworth filters and prints out the number of poles and the 3-dB cut-off frequency of the filters.

When MODPAT is unity, the results of the MD-918 performance calculations are printed. The performance of the MD-918 depends on the number of taps (NTAP) in the adaptive forward equalizer and the tap spacing (TAPW) normalized to the QPSK symbol duration (twice the inverse of the data rate). The actual MD-918 modem has been implemented with a three tap Forward Equalizer and a

normalized tap spacing of 0.5. However the user may specify other values for the the tap spacing. Another parameter which affects the performance of the MD-918 is the ratio of the available bandwidth to the data rate. To simulate the performance of the actual MD-918 modem the user should specify a bandwidth which is less than or no greater than twice the data rate. When the available bandwidth is much greater than the data rate, an improvement in performance can be obtained by modulating each information bit by a PN sequence, thus spreading the bandwidth of the transmitted signal to occupy all of the available bandwidth and to exploit the greater implicit diversity available over the larger bandwidth. The number of chips in the PN sequence (KGAIN) is equal to the integer part of the ratio of the bandwidth to the data rate. Thus whenever the user specifies a bandwidth which is greater than twice the data rate, the TROPO program calculates the number of chips per bit (KGAIN) and the PN sequence composed of KGAIN chips. The printout of the MD-918 modem performance calculations when pure troposcatter propagation (PTYPE=0) is specified is as follows.

The number of taps, and the tap spacing are used to calculate the signal covariance matrix for the AFE taps. The dimension of this matrix is equal to the number of taps multiplied by the number of explicit diversity channels. For example the signal covariance matrix for a system employing quad-diversity and a three-tap adaptive forward equalizer is a 12x12 matrix. However, if two or more of the explicit diversities are uncorrelated, the signal covariance matrix has a redundant block structure. For example if the link employs dual space/dual angle diversity (2S/2A) and the spacing between the antennas is such that the two space diversities are uncorrelated but the two angle diversities are correlated, the signal covariance matrix, for a three tap Forward Equalizer filter, has the following structure

$$
C = \begin{bmatrix} C_0 & C_2 & 0 & 0 \\ C_2 & C_1 & 0 & 0 \\ 0 & 0 & C_0 & C_2 \\ 0 & 0 & C_2 & C_1 \end{bmatrix}
$$

where C_0, C_1 and C_2 are 3x3 matrices. C_0 is the signal covariance matrix for the thre taps corresponding to the lower beam on one of the spaced antennas, C_1 is the covariance matrix for the three taps corresponding to the upper beam on the same antenna and C_2 is the covariance matrix whose elements are proportional to the cross-correlation between the signals on the lower beam and upper beam taps. Only the largest non-redundant block in the signal covariance matrix is printed out. This matrix is normalized to unity signal power.

The same procedure is used to calculate and print out the thermal noise covariance matrix A_T (normalized to unity noise power), the ISI covariance matrix A_{ISI} (normalized to unity signal-to-noise ratio) and the interference covariance matrix A_J (normalized to unity interference power) which exhibit similar block structure. These normalized covariance matrices are used to form the normalized SNR matrix $A^{-1}C$ where A^{-1} is the inverse of the total noise matrix defined as

$$
A = A_T + \frac{E_b}{N_0} A_{ISI} + \frac{JT}{N_0} A_J
$$

where E_b/N_0 is the average signal-to-thermal-noise ratio per channel bit (SNR), and JT/N_0 is the interference power-to-noise power ratio.

The short-term performance of the MD-918 is then calculated from the eigenvalues of the normalized SNR matrix $A^{-1}C$ as a function of the short-term average signal-to-noise ratio E_b/N_0 (in dB). Note that since the total noise matrix A depends on E_b/N_0, the eigenvalues of the normalized SNR matrix $A^{-1}C$ will differ for different values of E_b/N_0. The number of eigenvalues is equal to the dimension of the SNR matrix $A^{-1}C$. However because of the redundant block structure some of the eigenvalues will be equal (see Section 2.8.1). Only the distinct eigenvalues are printed out. The short-term performance measures that are calculated and printed out as a function of E_b/N_0 (for values between 28 dB and -4 dB) are the short-term average bit error rate, the 1000-bit block error probability, the outage probability and the fade outage per call minute. These performance measures are defined in detail in Section 2.8.1 of this document. Note that for each value of E_b/N_0, the performance of various diversity configurations, determined by the value specified for DIVTYP, is calculated. Also note that the outage probability and the fade outage per call minute depend on the choice of bit error rate threshold. Hence, when NERT=0 is specified, the outage probability and fade outage per call minute for three different error rate thresholds is calculated. The average bit error rate and 1000 bit block error probability are independent of the error rate threshold.

The long-term performance of the MD-918 is then calculated by averaging the various short-term performance measures over the yearly distribution of E_b/N_0 as discussed in Section 2.8.2 of this document. Thus long term performance is affected by the yearly median value of E_b/N_0 and its standard deviation.

When mixed troposcatter-diffraction is specified (PTYPE=1), the program calculates and prints out the short-term performance measures described in Section 2.8.1 as a function of the troposcatter component SNR, $a_S E_b/N_0$ (for values between 28 dB and -4 dB in steps of 2 dB), and the diffraction component SNR,

$a_D E_b/N_0$ (calculated for values between 15 dB and -15 dB in steps of 3 dB but printed out only for values of 6 dB, 0dB and -6 dB). The long-term performance of the MD-918 is then calculated by averaging over the yearly distribution of $a_S E_b/N_0$ and $a_D E_b/N_0$ as discussed in Section 2.8.2 of this document and the results are then printed out.

When MODPAT is two, the performance of the AN/TRC-170-DAR modem is calculated. The performance of the AN/TRC-170 depends on whether one or two frequencies per explicit diversity (TRCTYP=0 or 1, respectively) are used to transmit data, and the ratio of the rms (2-sigma) multipath spread to the symbol interval*. From these two parameters, the short-term and long-term performance of the DAR modem are calculated in similar fashion as for the MD-918. The short-term average bit error rate, outage probability and outage per call minute are printed as a function of the short-term average E_b/N_0 (in dB) for the case of dual space (2S) and dual space/dual frequency (2S/2F) diversity. The yearly average outage probability, POUT, and average fade outage per call minute are then printed for the various error rate thresholds selected.

3.4.2 Summary Pages Output File

This output file is written to disk as file SUMPAG.OUT. It is suggested that the user rename this file to something unique to the run it pertains to (or else list it and delete it) prior to the next TROPO run.

SUMPAG.OUT contains a summary of some of the more relevant input parameters such as frequency, transmitter power, bandwidth, antenna heights above ground, antenna diameters, transmit and

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* Note: The symbol interval is twice the QPSK symbol duration.

ceive site elevations above sea level, horizon elevation angles d climate type. It also contains a summary of the propagation lculations including troposcatter scattering angle, path asymmetry, atmospheric absorption loss, reference troposcatter path ss (no climate correction factors) and RMS delay spread for the wer (beam 1) and upper beams (beam 2), correlation between the rious angle and/or space diversity troposcatter signals, tropoatter coherence (correlation) bandwidth and the minimum freer~y separation required for frequency diversity. The yearly stribution of the troposcatter path loss and RSL, including imate correction factors and service probability are also inted. For a more detailed discussion of the troposcatter callations, the reader is referred to Section 2.5 of this document.

When mixed troposcatter-diffraction is specified (PTYPE = 1 11), SUMPAG.OUT also contains the yearly distribution of the ffraction component of the received signal and the relative lay between the diffraction and troposcatter components. The ffraction component path loss and RSL distributions include the imate correction factors and service probability correction. tails about the diffraction component calculations are discusd in Section 2.6 of this document.

When MODPAT is not zero, the second page of SUMPAG.OUT contains a summary of the long term (yearly average) performance of e modem specified by the user (MD-918 or TRC-170 DAR). More ecifically it gives the yearly average outage probability and arly average fade outage per call minute for the diversity congurations (DIVTYP) and error rate thresholds (NERT) specified. e details of these calculations for the MD-918 and DAR modems e discussed in Sections 2.8 and 2.9 of this document.

The third page of SUMPAG.OUT contains a summary of some of e control parameters used to perform the troposcatter propaga-

tion calculations. These are listed for debugging purposes. Pages 4, 5, etc. contain a print out of the normalized troposcatter power per unit delay profile for each of the receive beams as well as the correlation per unit delay for each pair of receive beams (see Section 2.5.5 and 2.5.6) as a function of delay. These are also listed for debugging purposes. To omit these profiles from the output, the user should enter PTYPE=10 for troposcatter propagation or PTYPE=11 for mixed troposcatter-diffraction.

3.4.3 Error Output

Checks for input errors are performed throughout the program. When fatal errors and/or data inconsistencies are encountered, error messages are printed to the terminal (unit LTERM) and to unit LOUT. Table 3-1 lists some of the possible error code printouts. All are fatal with the exception of ERRORS 21, 52, 53, 64, 77, 91, 106, 120, 121, 122, 123, and 125 which are warnings.

In addition to the numeric codes listed in Table 3-1, TROPO produces additional error messages with English text, usually to the LOUT or LDEBUG output file. These should be self-explanatory. Under certain conditions, your system may produce error messages not under the control of TROPO. See your system documentation for a description of Fortran run-time error messages.

It is recommended that the user take care to keep track of which output files go with which run. This can be accomplished by printing the files produced by each run immediately and labelling the listings with a unique identification. The disk files can then be deleted.

Table 3-1

TROPO Error Messages

(NOTE: Errors 1 through 91 are written by the SUBROUTINE ERROR.)

CHKDAT errors:

ERROR 1 - Illegal values of NT or NR in input file.
ERROR 2 - Transmitters not symmetric about the great circle plane.
ERROR 3 - Receivers not symmetric about the great circle plane.
ERROR 4 - Invalid combination of cross correlations desired.
ERROR 5 - Redundant cross correlation.
ERROR 6 - Transmitter antennas not of the same size.
ERROR 7 - Receiver antennas different or not symmetric about the great circle plane.
ERROR 8 - Misaligned input data.

MDTS errors:

ERROR 21 - WARNING: MD-918 performance calculations assume that RF filters do not introduce ISI degradation.
ERROR 22 - RMS multipath spread of scatter component is too small. To determine MD-918 performance use:
- a) QPSK system performance under Rayleigh flat-fading conditions if path is pure scatter path.
- b) QPSK system performance under Rician flat-fading conditions if path is mixed tropo/diffraction path.
- c) QPSK system performance in the additive white Gaussian noise channel if the diffraction component is more than 15 dB stronger than the scatter component.

MATOPS errors:

ERROR 31 - Too large a dimension in CHANGE.
ERROR 32 - Too large an array dimension in MATA.
ERROR 33 - SQTMAT has too large a dimension.
ERROR 34 - SQTMAT - matrix not positive-definite.

ATMOS errors:

ERROR 51 - Distance input must be positive.
ERROR 52 - WARNING: Atmospheric absorption loss overestimated for path lengths greater than 500 km.
ERROR 53 - WARNING: Atmospheric absorption loss calculation incorrect for frequencies greater than 35 GHz.

UNITCV error:

ERROR 56 - Invalid choice of LUNITS.

TRANSF errors:

ERROR 61 - Negative scatter angle: beams pointed too low.
ERROR 62 - PHIT negative: transmitter horizon too low.
ERROR 63 - PHIR negative: receiver horizon too low.
ERROR 64 - WARNING: ALFAO, BETAO or HCOM appear out of range.
ERROR 65 - Takeoff angles not calculated.

ANTPAR, GPATT errors:

ERROR 71 - Transmit antenna number outside range.
ERROR 72 - Receive antenna number outside range.

LOOPS errors:

ERROR 76 - Number of correlations requested too large; increase NCORMX or request fewer correlations.
ERROR 77 - WARNING: Number of delay cells, NDELMX may be too small for the delay spread.
ERROR 78 - Fatal integration error.
ERROR 80 - The symmetrically located azimuth beam missing in correlation; resubmit with the necessary beams specified.
ERROR 81 - Power term for correlation coefficient not evaluated.

RIPROF error:

ERROR 91 - WARNING: Largest height for which CN2 was specified is too low. CN2 profile assumed constant above this height.

Possible causes of Error 91:

1) Not enough CN2 samples. Increase KPROF in input file and add more data points to CN2. See HLOW and HHIGH in SUMPAG.OUT. These values specify the lowest and highest heights in the common volume.

(NOTE: Errors 101 through 131 are written by the SUBROUTINE ERRIO.)

UNITS errors:

ERROR 101 - Invalid distance units.
ERROR 102 - Invalid height/diameter units.
ERROR 103 - Invalid angle units.
ERROR 104 - Invalid frequency units.
ERROR 130 - Mixing English and metric units.

SECTOR error:

ERROR 105 - List directed read; check input file.

INDATA errors:

ERROR 106 - WARNING: Diffraction analysis and interference calculations cannot be run simultaneously. DIVTYP set to zero.
ERROR 107 - Invalid transmit power units.
ERROR 108 - Data rate out of range; either smaller than BW/30 or greater than twice the BW.
ERROR 109 - Invalid tapwidth value.
ERROR 110 - Invalid MDIST value.
ERROR 111 - Invalid ICLIME value.
ERROR 112 - Invalid PTYPE value.
ERROR 113 - Invalid ITOFF value.
ERROR 114 - Invalid NTERR value.
ERROR 115 - Invalid NOBS value.
ERROR 116 - Invalid DIVTYP value.
ERROR 117 - Invalid IBW value.
ERROR 118 - Invalid IFILTX or IFILRX value.
ERROR 119 - Invalid NERT value.
ERROR 120 - WARNING: IBW set equal to 1 since PTYPE = 1.
ERROR 121 - WARNING: NERT set equal to 2 since PTYPE = 1.
ERROR 122 - WARNING: Code for DIVTYP = 3 not implemented.
ERROR 123 - WARNING: Modem not allowed for DIVTYP > 2. MODPAT set to 0.
ERROR 124 - Each NPM must be 30 or less; for PTYPE = 0, greater than 5.
ERROR 125 - WARNING: For PTYPE = 1, if possible, each NPM should be greater than 5.
ERROR 126 - Total number of diffraction points (sum of NMPs) has exceeded array bounds of HI. Not all elevation points can be read in.
ERROR 127 - NPM(1) must be 1 and all others 0. Setting to these values.
ERROR 128 - DLT and DLR must be positive to calculate radio horizons (ITOFF = 2).
ERROR 129 - KPROF must be NPROF or less.
ERROR 130 - Mixing English and metric units.
ERROR 131 - DRATE out of range; either smaller than BW/4 or greater than BW.
ERROR 132 - This version of TROPO allows only horizontal antenna spacing.

SECTION 4
SOME EXAMPLES

In this section, we present a few examples which illustrate nore important features of the TROPO program. The token ιe>> interspered through the FOR002.Dat files indicates that output from the subprogram 'name' continues from a given until the next different one.

The following table outlines the major parameters of the e runs:

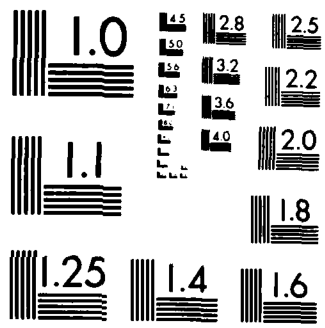
RUN NUMBER	PTYPE	MODPAT	JPOW	TAPOUT
1	10	1	-1000.0	T
2	11	1	-1000.0	F
3	10	1	-124.0	F
4	10	2	-1000.0	F

ole 1

This example illustrates the format of the input file when troposcatter propagation is specified (PTYPE = 0, or 10). ddition MODPAT = 1 is specified to illustrate the format of output files when the performance of the MD-918 is requested. input file and the two output files FOR002.DAT (unit LOUT) SUMPAG.OUT are listed next.

AD-A151 418 DIGITAL TROPOSCATTER PERFORMANCE MODEL USERS MANUAL(U) 3/4
SIGNATRON INC LEXINGTON MA P MONSEN ET AL. NOV 83
A-288-15 DCA100-80-C-0030

UNCLASSIFIED F/G 17/2.1 NL



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

TROPO.DAT *for* RUN 1

```
--------------------------- Input File Version 1.0 ----------------------------
START -- * -- * -- * -- * -- * -- * -- * -- * -- * -- * -- * -- * -- * --
* LINK NAME from transmit site to receive site (40 character maximum)
RUN 1: TROPO - MD-918
* MODPAT:        0 = Propagation only,
*                1 = Propagation + MD-918 -- Default
*                2 = Propagation + AN/TRC-170
*                3 = Propagation + user-defined modem.
1
* ICLIME:  Climate class; 0 = NBS (default), 1 = MIL-HDBK-417, 2 = New
1
* CLIMAT:  Climate code (See user's manual sec. 3.2; 4 character maximum)
CT
* GPF:  Frequency Correction Factor (default = 1.0)
1.0
* YMIN,DEMIN:    YO(90), DE at minima in kilometers
*                (used only when ICLIME=2)
0  0
* YZERO,Y900:    YO(90) at DE = 0, YO(90) at DE .ge. 900 kilometers
*                (used only when ICLIME=2)
0  0
* DISTU:  Distance units (SMI/KM/NMI); 4 character maximum
SMI
* HDU:  Height, elevation, diameter units (FT/M); 4 character maximum
FT
* ANGU:  Angle units (DEG/MRAD); 4 character maximum
DEG
* FREGU:  Frequency units (GHZ/MHZ); 4 character maximum
GHZ
* POWERU:  Transmit power units (W/dBm); 4 character maximum
DBM
* TXPOW:  Transmit power (defaults = 70 dBm, 10000 W)
50
* F:  Frequency (See user's manual sec 3.2 for limitations) (GHZ/MHZ)
0.875
* SP, NFIG:  Service Probability, Noise Figure (defaults = 0.95, 4dB)
.95  4.0
* TLL,RLL:  Transmitter, receiver line losses in dB (defaults = 0, 0)
1.5  1.5
* D:  Great circle distance at sea level between transmitter and receiver
*     (SMI/KM/NMI)
178.3
* HTO, HRO:  Transmitter, receiver site elevations above sea level (FT/M)
4822.82  7135.81
* HT,HR:  Transmitter, receiver antenna heights above ground (FT/M)
55  55
* PTYPE:  0 or 10 = Troposcatter; 1 or 11 = Mixed Troposcatter-Diffraction
*         PTYPE = 10 or 11 yields no correlation matrix in SUMPAG.OUT
10
TROPOSCATTER-ONLY SECTION -- * -- * -- Data for PTYPE = 1 or 10 * -- * -- * --
* ITOFF:  0 = input THET, THER (default), 2 = compute THET, THER
2
* THET, THER:  Transmitter, receiver horizon elevation angles (DEG/MRAD)
.06  .60
* DLT, DLR:  Transmitter, receiver distances to horizon (KM/SMI/NMI)
88.0  33.3
* HLT, HLR:  Transmitter, receiver horizon elevations above sea level (FT/M)
9128  9454
```

TROPO.DAT for RUN 1 (continued)

```
* NTERR:  Set flag:      0 = HTE, HRE are input,
*                        1 = use AVETX, AVERX
*                        2 = use terrain elevations (HI) to calculate HTE, HRE
2
* HTE, HRE:  Effective transmitter, receiver antenna heights
*            above average terrain elevations (FT/M)
0  0
* AVETX, AVERX:  Transmitter, receiver average foreground terrain elevations
*                above sea level (FT/M)
797.27  1619.79
* NP1, NP2:  Transmitter, receiver number of terrain elevations.
*            (Equivalent to NPM(1), NPM(2) in source code.) (defaults = 1,0)
9  9
* HI(1:NP1+NP2):  Terrain elevations beginning with transmit site elevation
*                 and ending with receive site elevation (FT/M)
4822.82  3535  3500  3485  3200  4160  4500  5000  9128
9454  5800  5700  5600  5650  5500  5400  5500  7135.81
DIFFRACTION SECTION -- * -- * -- * -- Data for PTYPE = 1 or 11 * -- * -- * --
* NOBS:  Number of diffraction obstacles;  maximum = 3 (default = 1)
2
* HL(1:NOBS):  Obstacle elevations above sea level beginning with transmit
*              horizon HLT and ending with receive horizon HLR (FT/M)
9128  9454
* DL(1:NOBS):  Great circle obstacle distances from transmitter (SMI/NMI/KM)
88.0  145.0
* DS(1:NOBS):  Effective horizontal obstacle extents (SMI/NMI/KM)
.04  .04
* NTERR:  Set flag:      0 = HTE, HRE ,HLEF are given next
*                        1 = use AVETX, AVERX, HLAV
*                        2 = use terrain elevations (HI) to calculate HTE, HRE
2
* HTE, HRE:  Effective transmitter, receiver antenna heights above
*            average terrain elevations.  Used only for NTERR = 0.  (FT/M)
0  0
* HLEF(1:NOBS):  Effective diffraction obstacle heights above average terrain
*                elevation.  Used only for NTERR = 0.  (FT/M)
0  0
* AVETX, AVERX:  Transmitter, receiver average terrain elevations above
*                sea level.  Used only for NTERR = 1.  (FT/M)
3400  7135
* HLAV(1:NOBS):  Average terrain elevation above sea level at each
*                diffraction point.  Used only for NTERR = 1.  (FT/M)
7800  8500
* NPM(1:NOBS+1):  Number of terrain elevations between each pair of diffraction
*                 obstacles. (Tx and Rx are end points.) (default = 1,0,0,0)
9  9  9
* HI(1:NPM(1) + ... + NPM(NOBS+1)):  Terrain elevation data beginning with
*       transmit site elevation and ending with receive site elevation (FT/M)
4822.82  3535  3500  3485  3200  4160  4500  5000  9128
9128  7250  7100  7250  7500  8000  8150  8000  9454
9454  5800  5700  5600  5650  5500  5400  5500  7135.81
DIVERSITY DATA INPUT SECTION -- * -- * -- * -- * -- * -- * -- * -- * -- * --
* DIVTYP: Diversity Type (default = 0)
*       0 = 2S     2S/2F        2S/2A   2S/2A/2F
*       1 = 2A     2F           2F/2A
*       2 = 2S/2P  2S/2P/2A
*     S = Space  F = Frequency  A = Angle  P = Polarization
0
```

TROPO.DAT for RUN 1 (continued)

```
* TDIAM:  Transmitter antenna aperture diameter (AT(1)) (FT/M)
88.58
* RDIAM:  Receiver antenna aperture diameter (AR(1)) (FT/M)
88.58
* TELH:  Transmitter antenna beam elevation above horizon (PSITEO(1)).  Input
*        an angle 4000 or greater to have TELH calculated.  (DEG/MRAD)
4000
* RELH:  Receiver antenna beam elevation above horizon (PSIREO(1)).  Input
*        an angle 4000 or greater to have RELH calculated.  (DEG/MRAD)
.27
* PHDIV:  Angle between upper and lower beams (Default = Beamwidth) (DEG/MRAD)
0.0
* TFLAG, TSEP:  TFLAG = Transmitter antenna spacing indicator
*               (TFLAG must be 0 for this version of TROPO.)
*               TSEP = Transmitter antenna separation (FT/M)
0  200
* RFLAG, RSEP:  RFLAG = Receiver antenna spacing indicator
*               (RFLAG must be 0 for this version of TROPO.)
*               RSEP = Receiver antenna separation (FT/M)
0  200
PROPAGATION DATA INPUT SECTION -- * -- * -- * -- * -- * -- * -- * -- * -- * --
* SEAN:  Refractivity at sea level (default = 0)
0
* ERFAC:  Effective Earth Radius Factor, K.  Recalculated if SEAN > 0.
*         (default = 1.33)
1.33
* SCPARM:  Wavenumber Spectrum Slope Parameter M for atmospheric turbulence.
*          Reset to 5 if Frequency < 1GHz.  (default = 3.66)
3.66
* NACCU, ERR:  Integration accuracy (truncation point) and resolution.
*              (defaults = 40, 0.001)
40  .001
* TAPOUT: Enter T to have simulator tap values output in FOR002.DAT (default),
*         enter F to suppress the calculations and output.
T
* SPE, MLAST: Simulator tap spacing in nanoseconds and
*             number of taps (defaults = 67 nsec, 16)
67  16
* KPROF:  Number of CN2 profile samples.  Maximum = NPROF  (See TROPAR INC)
0
* HLOW,DELH:  Lowest height above sea level at which CN2 is specified (FT/M),
*             Spacing of CN2 samples (FT/M)
0  0
* CN2(KPROF):  The atmospheric structure constant height profile samples (FT/M)
0
MODEM INPUT SECTION -- * -- * -- * -- Data for MODPAT > 0 * -- * -- * -- * -- *
* IBW:  Bandwidth constraint indicator (default = 0)
*       0 = No filter, 1 = 99%, 2 = FCC-19311, 3 = user specified
1
* IFILTX,IFILRX:  Transmit, receive filter impulse response (For IBW = 3 only)
*                 0 = MD-918 filter for receiver or transmitter
*                 1 = AN/TRC-170 filter for transmitter (not used for receiver)
*                 2 = AN/TRC-170 filter for receiver (not used for transmitter)
0  0
* FCTX,FCRX:  Transmitter, receiver 3dB cut-off frequencies (For IBW = 3 only)
*             (MHZ only)
0  0
* NPOLTX,NPOLRX:  Number of transmitter, receiver poles of Butterworth filter
```

TROPO.DAT for RUN 1 (continued)

```
*                    (For IBW = 3 only)
0  0
* BW:  Bandwidth, (default = 7.0 MHz)  (MHZ only)
7.0
* DRATE:  Data rate (bits/second)  (default = 6.6E6 bits/second)
6.3E6
* NERT:  Bit error rate threshold indicator:
*        0 = all, 1 = 1.0E-3, 2 = 1.0E-4 (default), 3 = 1.0E-5
0
MD-918 MODEM INPUT SECTION -- * -- * -- * -- Data for MODPAT = 1 * -- * -- * --
* TAPW:  Normalized tap width.  Range = 0.25 through 1.0.  (default = .5)
.5
* LISI:  Number of future ISI contributors considered  (default = 2)
2
AN/TRC-170 MODEM INPUT SECTION -- * -- * -- Data for MODPAT = 2 * -- * -- * --
* TRCTYP:  0 = single frequency, DAR modem;
*          1 = two frequencies, AN/TRC-170 modem (default)
1.0
INTERFERENCE PARAMETER INPUT SECTION -- * -- * -- * -- * -- * -- * -- * --
* JPOW:  Interference Power Density (default = -1000dBm/Hz for no interference)
-1000.
* JBW:  99% Interference Bandwidth (default = Bandwidth BW) (MHZ only)
10.5
* FJSEP:  Frequency separation between the interference signal and desired
*         signal (default = larger of BW and JBW) (MHZ only):
*               0. = co-channel interference
*               > BW and JBW = adjacent channel interference
21.0
* MANG:  Number of interferer azimuth, elevation pairs (default = 1)
5
* (XANG(I), ELANG(I),I=1,MANG):  Interferer azimuth, elevation angle (above
*       horizon) pairs.  (default = 0,0)  (DEG/MRAD)
.05  0  32.  0  8.  0  2.  0  .05 0
* MODSIG:  Interfering signal modulation format; 0 = FDM/FM, 1 = GPSK (default)
1
USER-SUPPLIED DIVERSITY INPUT SECTION -- * -- * -- * -- * -- * -- * -- * --
* NT, NR:  Number of transmit and receive ports;  Maximums = NTMX, NRMX
1  2
* AT(NT):  Transmitter antenna aperture diameter (FT/M)
28
* AR(NR):  Receiver antenna aperture diameter (FT/M)
2*30
* PSITEO(NT):  Transmitter beam elevation above horizon (DEG/MRAD)
4000
* PSIREO(NR):  Receiver beam elevation above horizon (DEG/MRAD)
2*.33966
* PSITAO(NT):  Transmitter beam azimuth (DEG/MRAD)
0
* PSIRAO(NR):  Receiver beam azimuth (DEG/MRAD)
0.  0.
* IPOLT(NT):  Transmitter polarizations (DEG/MRAD)
0
* IPOLR(NR):  Receiver polarizations (DEG/MRAD)
0  0
* ((IBR(I,J),J=I,NR),I=1,NR):  Beams and cross-beams at receiver.
*       Enter:  0 = correlation between receivers I and J is not desired
*               1 = only power (correlation) calculations are desired
*               2 = power (correlation) per unit delay calculations are desired
```

TROPO.DAT for RUN 1 (concluded)

```
2  2  2
* UTH(NT):   Transmitter horizontal offsets (FT/M)
0
* UTV(NT):   Transmitter vertical offsets (FT/M)
0
* UTL(NT):   Transmitter longitudinal offsets (FT/M)
0
* URH(NR):   Receiver horizontal offsets (FT/M)
0  0
* URV(NR):   Receiver vertical offsets (FT/M)
0  0
* URL(NR):   Receiver longitudinal offsets (FT/M)
0  0
END
```

***** Ignoring PSITEO and PSIREO input. Calculating angles.

FOR002.DAT for RUN 1

```
*** INPUT PARAMETERS *** 15-NOV-83  22:14:57
                                                                    << OUTDAT>>

                              PATH PARAMETERS
                              ---------------

LINK NAME (LNAME): RUN 1: TROPO - MD-918

PATH/MODEM INDICATOR (MODPAT):        1
  0 = Path only
  1 = Path + MD-918 modem
  2 = Path + AN/TRC-170 or DAR modem
  3 = Path + user defined modem

CLIMATE CLASS (ICLIME):               1
  0 = NBS TN101 CLIMATE
  1 = MIL-HDBK-417 CLIMATE
  2 = NEW USER-SUPPLIED CLIMATE

CLIMATE (CLIMAT):      CT

 NBS CLIMATES:
   CT    = CONTINENTAL TEMPERATE
   MTL   = MARITIME TEMPERATE OVERLAND
   MTS   = MARITIME TEMPERATE OVERSEA
   MSL   = MARITIME SUBTROPICAL OVERLAND
   CT2   = CONTINENTAL TEMPERATE TIME BLOCK 2
   DS    = DESERT, SAHARA
   EQU   = EQUATORIAL
   CS    = CONTINENTAL SUBTROPIC
   CTD   = MIXED CLIMATES - CT AND DS
   MTLD  = MIXED CLIMATES - MTL AND DS

 MIL-HDBK-417 CLIMATES:
   CT    = CONTINENTAL TEMPERATE
   MTL   = MARITIME TEMPERATE OVERLAND
   MTS   = MARITIME TEMPERATE OVERSEA
   MS    = MARITIME SUBTROPICAL
   DS    = DESERT, SAHARA
   EQU   = EQUATORIAL
   CS    = CONTINENTAL SUBTROPICAL
   MED   = MEDITERRANEAN
   POL   = POLAR

I/O UNITS INDICATOR (LUNITS):   8 = smi   ft    deg   GHz
   0 = smi  ft   mrad  GHz
   1 = km   m    mrad  GHz
   2 = nmi  ft   mrad  GHz
   8 = smi  ft   deg   GHz
   9 = km   m    deg   GHz
  10 = nmi  ft   deg   GHz
  16 = smi  ft   mrad  MHz
  17 = km   m    mrad  MHz
  18 = nmi  ft   mrad  MHz
  24 = smi  ft   deg   MHz
  25 = km   m    deg   MHz
```

FOR002.DAT for RUN 1 (continued)

```
26 = nmi ft  deg  MHz
```

FOR002.DAT for RUN 1 (continued)

```
TRANSMIT POWER (PXMIT):                                   50.00 dBm
TRANSMIT POWER (WLT):                                    100.00 W

FREQUENCY (F):                                             0.87 GHz

SERVICE PROBABILITY (SP):                                  0.950
NOISE FIGURE (NFIG):                                       4.00 dB

TRANSMITTER LINE LOSS (TLL):                               1.50 dB
RECEIVER LINE LOSS (RLL):                                  1.50 dB

TERMINAL DISTANCE (D):                                   178.30 smi

SITE ELEVATION ABOVE SEA LEVEL:
  TRANSMITTER (HTO)                                     4822.82 ft
  RECEIVER    (HRO)                                     7135.81 ft

ANTENNA HEIGHT ABOVE GROUND:
  TRANSMITTER (HT)                                        55.00 ft
  RECEIVER    (HR)                                        55.00 ft

ANTENNA HEIGHTS ABOVE SEA LEVEL:
  TX HTS=HTO+HT                                         4877.82 ft
  RX HRS=HRO+HR                                         7190.81 ft

PATH CALCULATION INDICATOR (PTYPE):                    0
  0 = TROPOSCATTER ONLY
  1 = MIXED TROPOSCATTER-DIFFRACTION OR DIFFRACTION ONLY
      PTYPE = 10 OR 11 EQUIVALENT TO PTYPE = 0 OR 1
      WITH POWER VS DELAY PROFILE OUTPUT SUPPRESSED

TAKE-OFF ANGLES CALCULATION INDICATOR (ITOFF):         2
   0 = SPECIFIED IN INPUT
   1 = CALCULATED USING K (ERFAC) = 1.33
   2 = CALCULATED USING INPUT SPECIFIED K (ERFAC) VALUE
   3 = UNCHANGED FROM PREVIOUS VALUE

DISTANCE TO HORIZON,MEASURED AT SEA LEVEL
  TRANSMITTER (DLT):                                      88.00 smi
  RECEIVER (DLR):                                         33.30 smi

HEIGHT ABOVE SEA LEVEL OF
  TRANSMIT HORIZON OBSTACLE (HLT):                      9128.00 ft
  RECEIVE HORIZON OBSTACLE (HLR):                       9454.00 ft

HTE,HRE DATA INDICATOR (NTERR):                        2
  0 = USER-SUPPLIED
  1 = AVETX,AVERX DATA
  2 = TERRAIN ELEVATION DATA
```

```
EVENLY SPACED TERRAIN ELEVATION ABOVE SEA LEVEL DATA IN ft
          NP1 =  9                 NP2 =  9
  TX - RADIO HORIZON      RADIO HORIZON - RX
          HI(1: 9)                HI(10:18)
         4822.82                 9454.00
         3535.00                 5800.00
         3500.00                 5700.00
         3485.00                 5600.00
         3200.00                 5650.00
         4160.00                 5500.00
         4500.00                 5400.00
         5000.00                 5500.00
         9128.00                 7135.81

DIVERSITY TYPE (DIVTYP):                              0
  0 = DIVERSITY OPTIONS:
      2S/2F, 2S, 2S/2A, 2S/2A/2F
  1 = DIVERSITY OPTIONS:
      2A, 2F, 2F/2A
  2 = DIVERSITY OPTIONS:
      2S/2P, 2S/2P/2A
  S = SPACE F = FREQUENCY A = ANGLE P = POLARIZATION

NUMBER OF TRANSMIT PORTS (NT):                        1
NUMBER OF RECEIVE PORTS  (NR):                        4

TRANSMIT ANTENNA DIAMETER (AT): PORT 1              88.58 ft

RECEIVE ANTENNA DIAMETER (AR):  PORT 1              88.58 ft
RECEIVE ANTENNA DIAMETER (AR):  PORT 2              88.58 ft
RECEIVE ANTENNA DIAMETER (AR):  PORT 3              88.58 ft
RECEIVE ANTENNA DIAMETER (AR):  PORT 4              88.58 ft

ANTENNA BORESIGHT ELEVATION ABOVE REFERENCE HORIZON
  TRANSMIT (PSITEO): PORT 1                           0.2258 deg  --> Angle calculated

  RECEIVE  (PSIREO): PORT 1                           0.2258 deg  --> Angle calculated
  RECEIVE  (PSIREO): PORT 2                           1.3547 deg  --> Angle calculated
  RECEIVE  (PSIREO): PORT 3                           0.2258 deg  --> Angle calculated
  RECEIVE  (PSIREO): PORT 4                           1.3547 deg  --> Angle calculated

ANTENNA BORESIGHT AZIMUTH, DEFINES
THE ANGLE TO THE GREAT-CIRCLE PLANE
 POSITIVE COUNTER-CLOCKWISE FOR TRANSMIT
 POSITIVE CLOCKWISE FOR RECEIVE
  TRANSMIT (PSITAO): PORT 1                           0.0000 deg

  RECEIVE  (PSIRAO): PORT 1                           0.0000 deg
  RECEIVE  (PSIRAO): PORT 2                           0.0000 deg
  RECEIVE  (PSIRAO): PORT 3                           0.0000 deg
  RECEIVE  (PSIRAO): PORT 4                           0.0000 deg

POLARIZATIONS
  TRANSMIT (IPOLT): PORT 1                            0

  RECEIVE  (IPOLR): PORT 1                            0
  RECEIVE  (IPOLR): PORT 2                            0
  RECEIVE  (IPOLR): PORT 3                            0
```

FOR002.DAT for RUN 1 (continued)

```
  RECEIVE  (IPOLR): PORT 4                          0

ANGLE BETWEEN UPPER AND LOWER BEAM (PHDIV):         1.1289 deg

BEAM AND CROSS-CORRELATION BEAM INDICATORS
  0 = NO CALCULATION
  1 = POWER (CORRELATION) ONLY
  2 = DELAY (CROSS) POWER SPECTRUM
         IBR(1,1)  =  2
         IBR(1,2)  =  2
         IBR(1,3)  =  2
         IBR(1,4)  =  0
         IBR(2,2)  =  2
         IBR(2,3)  =  0
         IBR(2,4)  =  0
         IBR(3,3)  =  0
         IBR(3,4)  =  0
         IBR(4,4)  =  0
```

FOR002.DAT for RUN 1 (continued)

```
TRANSMITTER OFFSETS (RELATIVE LOCATION)
               HORIZONTAL        VERTICAL     LONGITUDINAL
                  (UTH)            (UTV)          (UTL)
  PORT 1         0.00 ft         55.00 ft        0.00 ft

RECEIVER OFFSETS (RELATIVE LOCATION)
               HORIZONTAL        VERTICAL     LONGITUDINAL
                  (URH)            (URV)          (URL)
  PORT 1       100.00 ft         55.00 ft        0.00 ft
  PORT 2       100.00 ft         55.00 ft        0.00 ft
  PORT 3      -100.00 ft         55.00 ft        0.00 ft
  PORT 4      -100.00 ft         55.00 ft        0.00 ft

EFFECTIVE EARTH RADIUS FACTOR K (ERFAC):                  1.3300
WAVENUMBER SPECTRUM SLOPE PARAMETER M (SCPARM):           5.00
PARAMETER FOR TERMINATION OF NUMERICAL INTEGRATION
(NACCU)                                                  40
INTEGRATION RESOLUTION (ERR):                             0.0010
```

2	2S	2	2.0	1.00E-04	7.83E-01	1.00E+00	1.00E+00	1.93E-02
2	2S	2	2.0	1.00E-05	8.88E-01	1.00E+00	1.00E+00	1.93E-02
2	2S/2A	4	2.0	1.00E-03	4.67E-01	9.99E-01	1.00E+00	7.27E-03
2	2S/2A	4	2.0	1.00E-04	6.94E-01	1.00E+00	1.00E+00	7.27E-03
2	2S/2A	4	2.0	1.00E-05	8.37E-01	1.00E+00	1.00E+00	7.27E-03
4	2S/2A/2F	8	2.0	1.00E-03	4.25E-01	9.99E-01	1.00E+00	3.48E-03
4	2S/2A/2F	8	2.0	1.00E-04	7.35E-01	1.00E+00	1.00E+00	3.48E-03
4	2S/2A/2F	8	2.0	1.00E-05	9.01E-01	1.00E+00	1.00E+00	3.48E-03

<< MDTS>>

IGLE DIVERSITY EIGENVALUES
WER BEAM (U(1-K3)) 8.502749E-01 9.556210E-02 8.741238E-03
PER BEAM (U(K2-K6)) 1.808650E-01 2.170067E-02 1.430108E-03

ACE AND/OR FREQUENCY DIVERSITY EIGENVALUES (U(K7-K9))
8.49005E-01 1.08853E-01 9.84715E-03

<< BERCAL>>

IN / AM / V / D)	DIV TYPE (XTYPE)	EXPLC DIV (ITOT)	Eb/No (SNR)	ERROR RATE THRESHOLD (P)	OUTAGE PROBABILITY (PFO)	FADE OUTAGE PER CALL-MINUTE (FCMIN)	BLOCK ERROR PROBABILITY (SUM2)	A.E BIT ERROR RATE (BERAV)
4	2S/2F	4	0.0	1.00E-03	9.04E-01	1.00E+00	1.00E+00	2.72E-02
4	2S/2F	4	0.0	1.00E-04	9.85E-01	1.00E+00	1.00E+00	2.72E-02
4	2S/2F	4	0.0	1.00E-05	9.98E-01	1.00E+00	1.00E+00	2.72E-02
2	2S	2	0.0	1.00E-03	8.49E-01	1.00E+00	1.00E+00	4.46E-02
2	2S	2	0.0	1.00E-04	9.49E-01	1.00E+00	1.00E+00	4.46E-02
2	2S	2	0.0	1.00E-05	9.84E-01	1.00E+00	1.00E+00	4.46E-02
2	2S/2A	4	0.0	1.00E-03	7.84E-01	1.00E+00	1.00E+00	2.30E-02
2	2S/2A	4	0.0	1.00E-04	9.24E-01	1.00E+00	1.00E+00	2.30E-02
2	2S/2A	4	0.0	1.00E-05	9.75E-01	1.00E+00	1.00E+00	2.30E-02
4	2S/2A/2F	8	0.0	1.00E-03	8.44E-01	1.00E+00	1.00E+00	1.52E-02
4	2S/2A/2F	8	0.0	1.00E-04	9.73E-01	1.00E+00	1.00E+00	1.52E-02
4	2S/2A/2F	8	0.0	1.00E-05	9.96E-01	1.00E+00	1.00E+00	1.52E-02

<< MDTS>>

IGLE DIVERSITY EIGENVALUES
WER BEAM (U(1-K3)) 8.516631E-01 9.648035E-02 8.793822E-03
PER BEAM (U(K2-K6)) 1.814105E-01 2.180007E-02 1.447932E-03

ACE AND/OR FREQUENCY DIVERSITY EIGENVALUES (U(K7-K9))
8.50381E-01 1.10093E-01 9.90334E-03

<< BERCAL>>

IN / AM / V / D)	DIV TYPE (XTYPE)	EXPLC DIV (ITOT)	Eb/No (SNR)	ERROR RATE THRESHOLD (P)	OUTAGE PROBABILITY (PFO)	FADE OUTAGE PER CALL-MINUTE (FCMIN)	BLOCK ERROR PROBABILITY (SUM2)	AVE BIT ERROR RATE (BERAV)

2	2S/2A	4	6.0	1.00E-05	2.38E-01	9.62E-01	3.15E-01	3.15E-04
4	2S/2A/2F	8	6.0	1.00E-03	1.00E-02	1.14E-01	4.92E-02	4.92E-05
4	2S/2A/2F	8	6.0	1.00E-04	5.39E-02	4.86E-01	4.92E-02	4.92E-05
4	2S/2A/2F	8	6.0	1.00E-05	1.48E-01	8.53E-01	4.92E-02	4.92E-05

<< MDTS>>

ANGLE DIVERSITY EIGENVALUES
LOWER BEAM (U(1-K3)) 8.450706E-01 9.206095E-02 8.532940E-03
UPPER BEAM (U(K2-K6)) 1.788374E-01 2.132112E-02 1.361285E-03

SPACE AND/OR FREQUENCY DIVERSITY EIGENVALUES (U(K7-K9))
8.43843E-01 1.04190E-01 9.62220E-03

<< BERCAL>>

MAIN BEAM DIV (ID)	DIV TYPE (XTYPE)	EXPLC DIV (ITOT)	Eb/No (SNR)	ERROR RATE THRESHOLD (P)	OUTAGE PROBABILITY (PFO)	FADE OUTAGE PER CALL-MINUTE (FCMIN)	BLOCK ERROR PROBABILITY (SUM2)	AVE BIT ERROR RATE (BERAV)
4	2S/2F	4	4.0	1.00E-03	2.22E-01	9.50E-01	1.00E+00	1.89E-03
4	2S/2F	4	4.0	1.00E-04	4.58E-01	9.99E-01	1.00E+00	1.89E-03
4	2S/2F	4	4.0	1.00E-05	6.67E-01	1.00E+00	1.00E+00	1.89E-03
2	2S	2	4.0	1.00E-03	3.36E-01	9.93E-01	1.00E+00	7.14E-03
2	2S	2	4.0	1.00E-04	5.17E-01	1.00E+00	1.00E+00	7.14E-03
2	2S	2	4.0	1.00E-05	6.63E-01	1.00E+00	1.00E+00	7.14E-03
2	2S/2A	4	4.0	1.00E-03	1.85E-01	9.14E-01	1.00E+00	1.74E-03
2	2S/2A	4	4.0	1.00E-04	3.68E-01	9.96E-01	1.00E+00	1.74E-03
2	2S/2A	4	4.0	1.00E-05	5.40E-01	1.00E+00	1.00E+00	1.74E-03
4	2S/2A/2F	8	4.0	1.00E-03	9.81E-02	7.10E-01	5.19E-01	5.19E-04
4	2S/2A/2F	8	4.0	1.00E-04	2.96E-01	9.85E-01	5.19E-01	5.19E-04
4	2S/2A/2F	8	4.0	1.00E-05	5.26E-01	1.00E+00	5.19E-01	5.19E-04

<< MDTS>>

ANGLE DIVERSITY EIGENVALUES
LOWER BEAM (U(1-K3)) 8.481739E-01 9.415947E-02 8.659323E-03
UPPER BEAM (U(K2-K6)) 1.800434E-01 2.154879E-02 1.402692E-03

SPACE AND/OR FREQUENCY DIVERSITY EIGENVALUES (U(K7-K9))
8.46921E-01 1.06974E-01 9.75913E-03

<< BERCAL>>

MAIN BEAM DIV (ID)	DIV TYPE (XTYPE)	EXPLC DIV (ITOT)	Eb/No (SNR)	ERROR RATE THRESHOLD (P)	OUTAGE PROBABILITY (PFO)	FADE OUTAGE PER CALL-MINUTE (FCMIN)	BLOCK ERROR PROBABILITY (SUM2)	AVE BIT ERROR RATE (BERAV)
4	2S/2F	4	2.0	1.00E-03	5.80E-01	1.00E+00	1.00E+00	8.35E-03
4	2S/2F	4	2.0	1.00E-04	8.28E-01	1.00E+00	1.00E+00	8.35E-03
4	2S/2F	4	2.0	1.00E-05	9.40E-01	1.00E+00	1.00E+00	8.35E-03
2	2S	2	2.0	1.00E-03	6.02E-01	1.00E+00	1.00E+00	1.93E-02

FOR002.DAT for RUN 1 (continued)

<< MDTS>>

ANGLE DIVERSITY EIGENVALUES
LOWER BEAM (U(1-K3)) 8.346134E-01 8.480888E-02 8.054355E-03
UPPER BEAM (U(K2-K6)) 1.748305E-01 2.052426E-02 1.213919E-03

SPACE AND/OR FREQUENCY DIVERSITY EIGENVALUES (U(K7-K9))
8.33470E-01 9.48006E-02 9.09278E-03

<< BERCAL>>

MAIN BEAM DIV (ID)	DIV TYPE (XTYPE)	EXPLC DIV (ITOT)	Eb/No (SNR)	ERROR RATE THRESHOLD (P)	OUTAGE PROBABILITY (PFO)	FADE OUTAGE PER CALL-MINUTE (FCMIN)	BLOCK ERROR PROBABILITY (SUM2)	AVE BIT ERROR RATE (BERAV)
4	2S/2F	4	8.0	1.00E-03	7.35E-03	8.47E-02	4.00E-02	4.00E-05
4	2S/2F	4	8.0	1.00E-04	3.05E-02	3.10E-01	4.00E-02	4.00E-05
4	2S/2F	4	8.0	1.00E-05	7.65E-02	6.15E-01	4.00E-02	4.00E-05
2	2S	2	8.0	1.00E-03	5.33E-02	4.82E-01	6.29E-01	6.29E-04
2	2S	2	8.0	1.00E-04	1.13E-01	7.64E-01	6.29E-01	6.29E-04
2	2S	2	8.0	1.00E-05	1.86E-01	9.15E-01	6.29E-01	6.29E-04
2	2S/2A	4	8.0	1.00E-03	7.64E-03	8.79E-02	4.30E-02	4.30E-05
2	2S/2A	4	8.0	1.00E-04	2.91E-02	2.98E-01	4.30E-02	4.30E-05
2	2S/2A	4	8.0	1.00E-05	6.86E-02	5.74E-01	4.30E-02	4.30E-05
4	2S/2A/2F	8	8.0	1.00E-03	4.90E-04	5.87E-03	2.99E-03	2.99E-06
4	2S/2A/2F	8	8.0	1.00E-04	4.49E-03	5.26E-02	2.99E-03	2.99E-06
4	2S/2A/2F	8	8.0	1.00E-05	1.88E-02	2.04E-01	2.99E-03	2.99E-06

<< MDTS>>

ANGLE DIVERSITY EIGENVALUES
LOWER BEAM (U(1-K3)) 8.406425E-01 8.901874E-02 8.340698E-03
UPPER BEAM (U(K2-K6)) 1.771313E-01 2.098932E-02 1.300320E-03

SPACE AND/OR FREQUENCY DIVERSITY EIGENVALUES (U(K7-K9))
8.39451E-01 1.00210E-01 9.41146E-03

<< BERCAL>>

MAIN BEAM DIV (ID)	DIV TYPE (XTYPE)	EXPLC DIV (ITOT)	Eb/No (SNR)	ERROR RATE THRESHOLD (P)	OUTAGE PROBABILITY (PFO)	FADE OUTAGE PER CALL-MINUTE (FCMIN)	BLOCK ERROR PROBABILITY (SUM2)	AVE BIT ERROR RATE (BERAV)
4	2S/2F	4	6.0	1.00E-03	5.05E-02	4.63E-01	3.17E-01	3.17E-04
4	2S/2F	4	6.0	1.00E-04	1.50E-01	8.58E-01	3.17E-01	3.17E-04
4	2S/2F	4	6.0	1.00E-05	2.90E-01	9.84E-01	3.17E-01	3.17E-04
2	2S	2	6.0	1.00E-03	1.48E-01	8.54E-01	1.00E+00	2.27E-03
2	2S	2	6.0	1.00E-04	2.70E-01	9.77E-01	1.00E+00	2.27E-03
2	2S	2	6.0	1.00E-05	3.92E-01	9.97E-01	1.00E+00	2.27E-03
2	2S/2A	4	6.0	1.00E-03	4.67E-02	4.37E-01	3.15E-01	3.15E-04
2	2S/2A	4	6.0	1.00E-04	1.29E-01	8.09E-01	3.15E-01	3.15E-04

FOR002.DAT for RUN 1 (continued)

ANGLE DIVERSITY EIGENVALUES
LOWER BEAM (U(1-K3)) 8.175302E-01 7.287319E-02 7.064153E-03
UPPER BEAM (U(K2-K6)) 1.683630E-01 1.913067E-02 9.529068E-04

SPACE AND/OR FREQUENCY DIVERSITY EIGENVALUES (U(K7-K9))
8.16513E-01 7.99659E-02 7.96061E-03

<< BERCAL>>

MAIN BEAM DIV (ID)	DIV TYPE (XTYPE)	EXPLC DIV (ITOT)	Eb/No (SNR)	ERROR RATE THRESHOLD (P)	OUTAGE PROBABILITY (PFO)	FADE OUTAGE PER CALL-MINUTE (FCMIN)	BLOCK ERROR PROBABILITY (SUM2)	AVE BIT ERROR RATE (BERAV)
4	2S/2F	4	12.0	1.00E-03	5.43E-05	6.51E-04	3.11E-04	3.11E-07
4	2S/2F	4	12.0	1.00E-04	4.00E-04	4.78E-03	3.11E-04	3.11E-07
4	2S/2F	4	12.0	1.00E-05	1.57E-03	1.87E-02	3.11E-04	3.11E-07
2	2S	2	12.0	1.00E-03	4.22E-03	4.94E-02	3.53E-02	3.53E-05
2	2S	2	12.0	1.00E-04	1.18E-02	1.33E-01	3.53E-02	3.53E-05
2	2S	2	12.0	1.00E-05	2.40E-02	2.52E-01	3.53E-02	3.53E-05
2	2S/2A	4	12.0	1.00E-03	6.83E-05	8.20E-04	3.82E-04	3.82E-07
2	2S/2A	4	12.0	1.00E-04	4.62E-04	5.53E-03	3.82E-04	3.82E-07
2	2S/2A	4	12.0	1.00E-05	1.71E-03	2.04E-02	3.82E-04	3.82E-07
4	2S/2A/2F	8	12.0	1.00E-03	2.54E-07	3.05E-06	3.37E-06	3.37E-09
4	2S/2A/2F	8	12.0	1.00E-04	4.97E-06	5.97E-05	3.37E-06	3.37E-09
4	2S/2A/2F	8	12.0	1.00E-05	4.05E-05	4.86E-04	3.37E-06	3.37E-09

<< MDTS>>

ANGLE DIVERSITY EIGENVALUES
LOWER BEAM (U(1-K3)) 8.268685E-01 7.935387E-02 7.640080E-03
UPPER BEAM (U(K2-K6)) 1.718981E-01 1.990507E-02 1.097876E-03

SPACE AND/OR FREQUENCY DIVERSITY EIGENVALUES (U(K7-K9))
8.25784E-01 8.79382E-02 8.62361E-03

<< BERCAL>>

MAIN BEAM DIV (ID)	DIV TYPE (XTYPE)	EXPLC DIV (ITOT)	Eb/No (SNR)	ERROR RATE THRESHOLD (P)	OUTAGE PROBABILITY (PFO)	FADE OUTAGE PER CALL-MINUTE (FCMIN)	BLOCK ERROR PROBABILITY (SUM2)	AVE BIT ERROR RATE (BERAV)
4	2S/2F	4	10.0	1.00E-03	7.33E-04	8.76E-03	3.92E-03	3.92E-06
4	2S/2F	4	10.0	1.00E-04	4.12E-03	4.83E-02	3.92E-03	3.92E-06
4	2S/2F	4	10.0	1.00E-05	1.31E-02	1.46E-01	3.92E-03	3.92E-06
2	2S	2	10.0	1.00E-03	1.61E-02	1.77E-01	1.56E-01	1.56E-04
2	2S	2	10.0	1.00E-04	3.95E-02	3.83E-01	1.56E-01	1.56E-04
2	2S	2	10.0	1.00E-05	7.24E-02	5.94E-01	1.56E-01	1.56E-04
2	2S/2A	4	10.0	1.00E-03	8.49E-04	1.01E-02	4.55E-03	4.55E-06
2	2S/2A	4	10.0	1.00E-04	4.37E-03	5.11E-02	4.55E-03	4.55E-06
2	2S/2A	4	10.0	1.00E-05	1.30E-02	1.46E-01	4.55E-03	4.55E-06
4	2S/2A/2F	8	10.0	1.00E-03	1.36E-05	1.63E-04	1.20E-04	1.20E-07
4	2S/2A/2F	8	10.0	1.00E-04	1.92E-04	2.30E-03	1.20E-04	1.20E-07
4	2S/2A/2F	8	10.0	1.00E-05	1.17E-03	1.39E-02	1.20E-04	1.20E-07

FOR002.DAT for RUN 1 (continued)

SPACE AND/OR FREQUENCY DIVERSITY EIGENVALUES (U(K7-K9))
7.94103E-01 6.37604E-02 5.99975E-03

<< BERCAL>>

MAIN BEAM DIV (ID)	DIV TYPE (XTYPE)	EXPLC DIV (ITOT)	Eb/No (SNR)	ERROR RATE THRESHOLD (P)	OUTAGE PROBABILITY (PFO)	FADE OUTAGE PER CALL-MINUTE (FCMIN)	BLOCK ERROR PROBABILITY (SUM2)	AVE BIT ERROR RATE (BERAV)
4	2S/2F	4	16.0	1.00E-03	1.57E-07	1.88E-06	1.20E-06	1.20E-09
4	2S/2F	4	16.0	1.00E-04	1.80E-06	2.16E-05	1.20E-06	1.20E-09
4	2S/2F	4	16.0	1.00E-05	1.01E-05	1.21E-04	1.20E-06	1.20E-09
2	2S	2	16.0	1.00E-03	2.15E-04	2.58E-03	1.50E-03	1.50E-06
2	2S	2	16.0	1.00E-04	7.44E-04	8.89E-03	1.50E-03	1.50E-06
2	2S	2	16.0	1.00E-05	1.79E-03	2.13E-02	1.50E-03	1.50E-06
2	2S/2A	4	16.0	1.00E-03	2.16E-07	2.59E-06	1.56E-06	1.56E-09
2	2S/2A	4	16.0	1.00E-04	2.29E-06	2.75E-05	1.56E-06	1.56E-09
2	2S/2A	4	16.0	1.00E-05	1.22E-05	1.46E-04	1.56E-06	1.56E-09
4	2S/2A/2F	8	16.0	1.00E-03	4.38E-11	5.26E-10	1.18E-09	1.18E-12
4	2S/2A/2F	8	16.0	1.00E-04	1.29E-09	1.55E-08	1.18E-09	1.18E-12
4	2S/2A/2F	8	16.0	1.00E-05	1.54E-08	1.85E-07	1.18E-09	1.18E-12

<< MDTS>>

ANGLE DIVERSITY EIGENVALUES
LOWER BEAM (U(1-K3)) 8.068633E-01 6.593799E-02 6.305629E-03
UPPER BEAM (U(K2-K6)) 1.642664E-01 1.822752E-02 7.874375E-04

SPACE AND/OR FREQUENCY DIVERSITY EIGENVALUES (U(K7-K9))
8.05918E-01 7.16120E-02 7.07864E-03

<< BERCAL>>

MAIN BEAM DIV (ID)	DIV TYPE (XTYPE)	EXPLC DIV (ITOT)	Eb/No (SNR)	ERROR RATE THRESHOLD (P)	OUTAGE PROBABILITY (PFO)	FADE OUTAGE PER CALL-MINUTE (FCMIN)	BLOCK ERROR PROBABILITY (SUM2)	AVE BIT ERROR RATE (BERAV)
4	2S/2F	4	14.0	1.00E-03	3.19E-06	3.83E-05	2.08E-05	2.08E-08
4	2S/2F	4	14.0	1.00E-04	2.98E-05	3.57E-04	2.08E-05	2.08E-08
4	2S/2F	4	14.0	1.00E-05	1.42E-04	1.70E-03	2.08E-05	2.08E-08
2	2S	2	14.0	1.00E-03	9.93E-04	1.19E-02	7.48E-03	7.48E-06
2	2S	2	14.0	1.00E-04	3.11E-03	3.67E-02	7.48E-03	7.48E-06
2	2S	2	14.0	1.00E-05	6.93E-03	8.00E-02	7.48E-03	7.48E-06
2	2S/2A	4	14.0	1.00E-03	4.24E-06	5.09E-05	2.65E-05	2.65E-08
2	2S/2A	4	14.0	1.00E-04	3.66E-05	4.39E-04	2.65E-05	2.65E-08
2	2S/2A	4	14.0	1.00E-05	1.65E-04	1.97E-03	2.65E-05	2.65E-08
4	2S/2A/2F	8	14.0	1.00E-03	3.66E-09	4.39E-08	7.11E-08	7.11E-11
4	2S/2A/2F	8	14.0	1.00E-04	9.07E-08	1.09E-06	7.11E-08	7.11E-11
4	2S/2A/2F	8	14.0	1.00E-05	9.21E-07	1.11E-05	7.11E-08	7.11E-11

<< MDTS>>

FOR002.DAT for RUN 1 (continued)

<< BERCAL>>

MAIN BEAM DIV (ID)	DIV TYPE (XTYPE)	EXPLC DIV (ITOT)	Eb/No (SNR)	ERROR RATE THRESHOLD (P)	OUTAGE PROBABILITY (PFO)	FADE OUTAGE PER CALL-MINUTE (FCMIN)	BLOCK ERROR PROBABILITY (SUM2)	AVE BIT ERROR RATE (BERAV)
4	2S/2F	4	20.0	1.00E-03	2.61E-10	3.13E-09	2.75E-09	2.75E-12
4	2S/2F	4	20.0	1.00E-04	4.07E-09	4.88E-08	2.75E-09	2.75E-12
4	2S/2F	4	20.0	1.00E-05	2.94E-08	3.52E-07	2.75E-09	2.75E-12
2	2S	2	20.0	1.00E-03	8.50E-06	1.02E-04	5.47E-05	5.47E-08
2	2S	2	20.0	1.00E-04	3.40E-05	4.09E-04	5.47E-05	5.47E-08
2	2S	2	20.0	1.00E-05	9.26E-05	1.11E-03	5.47E-05	5.47E-08
2	2S/2A	4	20.0	1.00E-03	3.95E-10	4.74E-09	3.81E-09	3.81E-12
2	2S/2A	4	20.0	1.00E-04	5.62E-09	6.75E-08	3.81E-09	3.81E-12
2	2S/2A	4	20.0	1.00E-05	3.85E-08	4.62E-07	3.81E-09	3.81E-12
4	2S/2A/2F	8	20.0	1.00E-03	0.00E-01	0.00E-01	1.88E-13	1.88E-16
4	2S/2A/2F	8	20.0	1.00E-04	8.49E-14	1.02E-12	1.88E-13	1.88E-16
4	2S/2A/2F	8	20.0	1.00E-05	2.23E-12	2.68E-11	1.88E-13	1.88E-16

<< MDTS>>

ANGLE DIVERSITY EIGENVALUES
LOWER BEAM (U(1-K3))   7.814595E-01   5.354802E-02   4.344279E-03
UPPER BEAM (U(K2-K6))   1.540511E-01   1.623033E-02   4.591471E-04

SPACE AND/OR FREQUENCY DIVERSITY EIGENVALUES (U(K7-K9))
7.80661E-01   5.70777E-02   4.81153E-03

<< BERCAL>>

MAIN BEAM DIV (ID)	DIV TYPE (XTYPE)	EXPLC DIV (ITOT)	Eb/No (SNR)	ERROR RATE THRESHOLD (P)	OUTAGE PROBABILITY (PFO)	FADE OUTAGE PER CALL-MINUTE (FCMIN)	BLOCK ERROR PROBABILITY (SUM2)	AVE BIT ERROR RATE (BERAV)
4	2S/2F	4	18.0	1.00E-03	6.72E-09	8.06E-08	6.05E-08	6.05E-11
4	2S/2F	4	18.0	1.00E-04	9.13E-08	1.10E-06	6.05E-08	6.05E-11
4	2S/2F	4	18.0	1.00E-05	5.89E-07	7.07E-06	6.05E-08	6.05E-11
2	2S	2	18.0	1.00E-03	4.37E-05	5.24E-04	2.91E-04	2.91E-07
2	2S	2	18.0	1.00E-04	1.64E-04	1.97E-03	2.91E-04	2.91E-07
2	2S	2	18.0	1.00E-05	4.23E-04	5.06E-03	2.91E-04	2.91E-07
2	2S/2A	4	18.0	1.00E-03	9.58E-09	1.15E-07	8.04E-08	8.04E-11
2	2S/2A	4	18.0	1.00E-04	1.20E-07	1.44E-06	8.04E-08	8.04E-11
2	2S/2A	4	18.0	1.00E-05	7.37E-07	8.84E-06	8.04E-08	8.04E-11
4	2S/2A/2F	8	18.0	1.00E-03	3.54E-13	4.25E-12	1.61E-11	1.61E-14
4	2S/2A/2F	8	18.0	1.00E-04	1.52E-11	1.82E-10	1.61E-11	1.61E-14
4	2S/2A/2F	8	18.0	1.00E-05	2.05E-10	2.46E-09	1.61E-11	1.61E-14

<< MDTS>>

ANGLE DIVERSITY EIGENVALUES
LOWER BEAM (U(1-K3))   7.949754E-01   5.929873E-02   5.377321E-03
UPPER BEAM (U(K2-K6))   1.595623E-01   1.724462E-02   6.170361E-04

FOR002.DAT for RUN 1 (continued)

BEAM DIV (ID)	TYPE (XTYPE)	DIV (ITOT)	(SNR)	RATE THRESHOLD (P)	PROBABILITY (PFO)	PER CALL-MINUTE (FCMIN)	ERROR PROBABILITY (SUM2)	ERROR RATE (BERAV)
4	2S/2F	4	24.0	1.00E-03	3.42E-13	4.11E-12	4.76E-12	4.76E-15
4	2S/2F	4	24.0	1.00E-04	6.63E-12	7.95E-11	4.76E-12	4.76E-15
4	2S/2F	4	24.0	1.00E-05	5.56E-11	6.67E-10	4.76E-12	4.76E-15
2	2S	2	24.0	1.00E-03	3.09E-07	3.71E-06	1.93E-06	1.93E-09
2	2S	2	24.0	1.00E-04	1.35E-06	1.62E-05	1.93E-06	1.93E-09
2	2S	2	24.0	1.00E-05	3.93E-06	4.72E-05	1.93E-06	1.93E-09
2	2S/2A	4	24.0	1.00E-03	6.26E-13	7.51E-12	8.19E-12	8.19E-15
2	2S/2A	4	24.0	1.00E-04	1.15E-11	1.38E-10	8.19E-12	8.19E-15
2	2S/2A	4	24.0	1.00E-05	9.09E-11	1.09E-09	8.19E-12	8.19E-15
4	2S/2A/2F	8	24.0	1.00E-03	0.00E-01	0.00E-01	2.04E-17	2.04E-20
4	2S/2A/2F	8	24.0	1.00E-04	0.00E-01	0.00E-01	2.04E-17	2.04E-20
4	2S/2A/2F	8	24.0	1.00E-05	0.00E-01	0.00E-01	2.04E-17	2.04E-20

<<   MDTS>>

ANGLE DIVERSITY EIGENVALUES
LOWER BEAM (U(1-K3))   7.443966E-01   4.514369E-02   2.403481E-03
UPPER BEAM (U(K2-K6))   1.393964E-01   1.411290E-02   2.239031E-04

SPACE AND/OR FREQUENCY DIVERSITY EIGENVALUES (U(K7-K9))
7.43758E-01   4.76794E-02   2.62780E-03

<< BERCAL>>

MAIN BEAM DIV (ID)	DIV TYPE (XTYPE)	EXPLC DIV (ITOT)	Eb/No (SNR)	ERROR RATE THRESHOLD (P)	OUTAGE PROBABILITY (PFO)	FADE OUTAGE PER CALL-MINUTE (FCMIN)	BLOCK ERROR PROBABILITY (SUM2)	AVE BIT ERROR RATE (BERAV)
4	2S/2F	4	22.0	1.00E-03	9.65E-12	1.16E-10	1.16E-10	1.16E-13
4	2S/2F	4	22.0	1.00E-04	1.67E-10	2.00E-09	1.16E-10	1.16E-13
4	2S/2F	4	22.0	1.00E-05	1.31E-09	1.57E-08	1.16E-10	1.16E-13
2	2S	2	22.0	1.00E-03	1.62E-06	1.94E-05	1.02E-05	1.02E-08
2	2S	2	22.0	1.00E-04	6.81E-06	8.17E-05	1.02E-05	1.02E-08
2	2S	2	22.0	1.00E-05	1.93E-05	2.31E-04	1.02E-05	1.02E-08
2	2S/2A	4	22.0	1.00E-03	1.61E-11	1.93E-10	1.74E-10	1.74E-13
2	2S/2A	4	22.0	1.00E-04	2.52E-10	3.02E-09	1.74E-10	1.74E-13
2	2S/2A	4	22.0	1.00E-05	1.87E-09	2.25E-08	1.74E-10	1.74E-13
4	2S/2A/2F	8	22.0	1.00E-03	0.00E-01	0.00E-01	1.98E-15	1.98E-18
4	2S/2A/2F	8	22.0	1.00E-04	0.00E-01	0.00E-01	1.98E-15	1.98E-18
4	2S/2A/2F	8	22.0	1.00E-05	0.00E-01	0.00E-01	1.98E-15	1.98E-18

<<   MDTS>>

ANGLE DIVERSITY EIGENVALUES
LOWER BEAM (U(1-K3))   7.651944E-01   4.888579E-02   3.316493E-03
UPPER BEAM (U(K2-K6))   1.474182E-01   1.519925E-02   3.265149E-04

SPACE AND/OR FREQUENCY DIVERSITY EIGENVALUES (U(K7-K9))
7.64473E-01   5.17808E-02   3.64715E-03

4	2S/2F	4	28.0	1.00E-04	1.55E-15	1.87E-14	9.32E-15	9.32E-18
4	2S/2F	4	28.0	1.00E-05	1.01E-13	1.21E-12	9.32E-15	9.32E-18
2	2S	2	28.0	1.00E-03	1.27E-08	1.53E-07	7.89E-08	7.89E-11
2	2S	2	28.0	1.00E-04	5.77E-08	6.93E-07	7.89E-08	7.89E-11
2	2S	2	28.0	1.00E-05	1.74E-07	2.09E-06	7.89E-08	7.89E-11
2	2S/2A	4	28.0	1.00E-03	0.00E-01	0.00E-01	2.43E-14	2.43E-17
2	2S/2A	4	28.0	1.00E-04	0.00E-01	0.00E-01	2.43E-14	2.43E-17
2	2S/2A	4	28.0	1.00E-05	2.34E-13	2.81E-12	2.43E-14	2.43E-17
4	2S/2A/2F	8	28.0	1.00E-03	0.00E-01	0.00E-01	2.59E-21	2.59E-24
4	2S/2A/2F	8	28.0	1.00E-04	0.00E-01	0.00E-01	2.59E-21	2.59E-24
4	2S/2A/2F	8	28.0	1.00E-05	0.00E-01	0.00E-01	2.59E-21	2.59E-24

<< MDTS>>

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ANGLE DIVERSITY EIGENVALUES
LOWER BEAM (U(1-K3))     6.809615E-01   3.894774E-02   1.123567E-03
UPPER BEAM (U(K2-K6))    1.196751E-01   1.145922E-02   9.786320E-05

SPACE AND/OR FREQUENCY DIVERSITY EIGENVALUES (U(K7-K9))
  6.80492E-01   4.13745E-02   1.21969E-03
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<< BERCAL>>

MAIN BEAM DIV (ID)	DIV TYPE (XTYPE)	EXPLC DIV (ITOT)	Eb/No (SNR)	ERROR RATE THRESHOLD (P)	OUTAGE PROBABILITY (PFO)	FADE OUTAGE PER CALL-MINUTE (FCMIN)	BLOCK ERROR PROBABILITY (SUM2)	AVE BIT ERROR RATE (BERAV)
4	2S/2F	4	26.0	1.00E-03	5.20E-15	6.25E-14	2.02E-13	2.02E-16
4	2S/2F	4	26.0	1.00E-04	2.65E-13	3.19E-12	2.02E-13	2.02E-16
4	2S/2F	4	26.0	1.00E-05	2.39E-12	2.87E-11	2.02E-13	2.02E-16
2	2S	2	26.0	1.00E-03	6.10E-08	7.32E-07	3.79E-07	3.79E-10
2	2S	2	26.0	1.00E-04	2.72E-07	3.26E-06	3.79E-07	3.79E-10
2	2S	2	26.0	1.00E-05	8.11E-07	9.73E-06	3.79E-07	3.79E-10
2	2S/2A	4	26.0	1.00E-03	0.00E-01	0.00E-01	4.17E-13	4.17E-16
2	2S/2A	4	26.0	1.00E-04	5.29E-13	6.35E-12	4.17E-13	4.17E-16
2	2S/2A	4	26.0	1.00E-05	4.69E-12	5.62E-11	4.17E-13	4.17E-16
4	2S/2A/2F	8	26.0	1.00E-03	0.00E-01	0.00E-01	2.20E-19	2.20E-22
4	2S/2A/2F	8	26.0	1.00E-04	0.00E-01	0.00E-01	2.20E-19	2.20E-22
4	2S/2A/2F	8	26.0	1.00E-05	0.00E-01	0.00E-01	2.20E-19	2.20E-22

<< MDTS>>

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ANGLE DIVERSITY EIGENVALUES
LOWER BEAM (U(1-K3))     7.169344E-01   4.196123E-02   1.669456E-03
UPPER BEAM (U(K2-K6))    1.299972E-01   1.289247E-02   1.494377E-04

SPACE AND/OR FREQUENCY DIVERSITY EIGENVALUES (U(K7-K9))
  7.16382E-01   4.43652E-02   1.81755E-03
```

<< BERCAL>>

MAIN	DIV	EXPLC	Eb/No	ERROR	OUTAGE	FADE OUTAGE	BLOCK	AVE BIT

FOR002.DAT for RUN 1 (continued)

SHORT TERM OUTAGE PROBABILITIES VS Eb/No

<< MATCO>>

COVARIANCE MATRIX FOR AFE TAPS (C)

3.5586E-01	4.7278E-01	2.4061E-01	1.9180E-02	3.6372E-02	2.0395E-02
4.7278E-01	7.6262E-01	4.5742E-01	1.4252E-02	2.2919E-02	1.5735E-03
2.4061E-01	4.5742E-01	3.0996E-01	3.5899E-03	6.7799E-04	-1.3330E-02
1.9180E-02	1.4252E-02	3.5899E-03	4.1809E-02	7.2369E-02	4.4601E-02
3.6372E-02	2.2919E-02	6.7799E-04	7.2369E-02	1.4569E-01	1.0596E-01
2.0395E-02	1.5735E-03	-1.3330E-02	4.4601E-02	1.0596E-01	9.0350E-02

NOISE MATRIX FOR AFE TAPS (A)

9.0742E-01	5.0300E-01	4.5801E-02	0.0000E-01	0.0000E-01	0.0000E-01
5.0300E-01	9.0742E-01	5.0300E-01	0.0000E-01	0.0000E-01	0.0000E-01
4.5801E-02	5.0300E-01	9.0742E-01	0.0000E-01	0.0000E-01	0.0000E-01
0.0000E-01	0.0000E-01	0.0000E-01	9.0742E-01	5.0300E-01	4.5801E-02
0.0000E-01	0.0000E-01	0.0000E-01	5.0300E-01	9.0742E-01	5.0300E-01
0.0000E-01	0.0000E-01	0.0000E-01	4.5801E-02	5.0300E-01	9.0742E-01

ISI MATRIX FOR AFE TAPS (CSUM)

3.0997E-01	6.6703E-02	9.8419E-04	0.0000E-01	0.0000E-01	0.0000E-01
6.6703E-02	1.7254E-02	3.3206E-04	0.0000E-01	0.0000E-01	0.0000E-01
9.8419E-04	3.3206E-04	1.0842E-05	0.0000E-01	0.0000E-01	0.0000E-01
0.0000E-01	0.0000E-01	0.0000E-01	3.2948E-01	1.0391E-01	6.9893E-03
0.0000E-01	0.0000E-01	0.0000E-01	1.0391E-01	4.2192E-02	4.2148E-03
0.0000E-01	0.0000E-01	0.0000E-01	6.9893E-03	4.2148E-03	7.5101E-04

<< MDTS>>

DET C (DEX) = 4.2243E-10

<< MDTS>>

ANGLE DIVERSITY EIGENVALUES
LOWER BEAM (U(1-K3)) 6.359118E-01 3.577300E-02 7.395021E-04
UPPER BEAM (U(K2-K6)) 1.092404E-01 9.788798E-03 6.324105E-05

SPACE AND/OR FREQUENCY DIVERSITY EIGENVALUES (U(K7-K9))
6.35510E-01 3.82732E-02 8.01241E-04

<< BERCAL>>

MAIN BEAM DIV (ID)	DIV TYPE (XTYPE)	EXPLC DIV (ITOT)	Eb/No (SNR)	ERROR RATE THRESHOLD (P)	OUTAGE PROBABILITY (PFO)	FADE OUTAGE PER CALL-MINUTE (FCMIN)	BLOCK ERROR PROBABILITY (SUM2)	AVE BIT ERROR RATE (BERAV)
4	2S/2F	4	28.0	1.00E-03	0.00E-01	0.00E-01	9.32E-15	9.32E-18

FOR002.DAT for RUN 1 (continued)

```
                MD-918 MODEM OUTPUT PARAMETERS:  SECTION 2
                ------------------------------------------
                                                                   <<    MDTS>>

NUMBER OF CHIPS PER BIT (KGAIN):                        1

CHIP SEQUENCE (ASEQ)
   1             1
                                                                   <<   BOTAC>>

NO. OF AFE TAPS (K1) AND TAP WIDTH IN T UNITS (TAPW) =      3      0.50
                                                                   <<    MDTS>>

MODEM DEGRADATION (DGRMOD) =     0.00dB
PEAK-TO-AVERAGE LOSS (PEAKAV) =     1.25dB
```

FOR002.DAT for RUN 1 (continued)

FILTER DATA

<< BUTFIL>>

	TRANSMITTER		RECEIVER	
Filter type	0	(IFILTX)	0	(IFILRX)
Poles	2	(NPOLTX)	4	(NPOLRX)
Cut-off freq (MHz)	3.10	(FCUT1)	3.50	(FCUT2)

TRANSMISSION BANDWIDTH (MHz) (FCUT) = 7.0000

FILTER TYPE REFERS TO THE RECTANGULAR SECTION
= 0: FULL SYMBOL INTERVAL DURATION
= 1: HALF SYMBOL INTERVAL DURATION
= 2: NO RECTANGULAR SECTION

PEAK-TO-AVERAGE POWER RATIO (dB) (PEAKAV) = 1.2519

FOR002.DAT for RUN 1 (continued)

YEARLY DISTRIBUTION OF SHORT-TERM MEAN Eb/No

SERVICE PROBABILITY (SP) =	0.950
MEDIAN OF SHORT-TERM MEAN Eb/No (ASNR)	1.1349E+01
STANDARD DEVIATION (STSNR)	1.0509E+01
MEDIAN PATHLOSS (PMED)	231.32

PERCENTILE (NOT EXCEEDED) (TEMP1)	PATH LOSS (dB) (TLOSS)	RSL (dBm) (RSL)	MEAN Eb/No (SNR)
0.01	208.914	-69.853	33.753
0.10	212.180	-73.119	30.488
1.00	216.267	-77.206	26.400
10.00	222.416	-83.355	20.252
50.00	231.319	-92.258	11.349
90.00	243.364	-104.302	-0.696
99.00	255.051	-115.990	-12.383
99.90	263.792	-124.731	-21.124
99.99	271.148	-132.087	-28.480

TROPOSCATTER PROPAGATION OUTPUT PARAMETERS: SECTION 1

<<   POWER>>

ATMOSPHERIC ABSORPTION LOSS (AA): 1.304 dB
TRANSMIT BEAMWIDTH (BWT): 0.9031 deg
RECEIVE BEAMWIDTH (BWR): 0.9031 deg

NUMBER OF INTEGRATION CELLS (ITER): 16704

LONG TERM REFERENCE TROPOSCATTER PATH LOSS,
NO CLIMATE CORRECTION

REFERENCE PATH LOSS ON LOWER BEAM (TEMP1): 228.97 dB
REFERENCE PATH LOSS ON UPPER BEAM (TEMP2): 234.58 dB
CORRELATION COEFFICIENT BETWEEN LOWER AND
UPPER BEAM (RH1): 0.0421

APERTURE-TO-MEDIUM COUPLING LOSS (CPL): BEAM 1 1   11.39 dB
APERTURE-TO-MEDIUM COUPLING LOSS (CPL): BEAM 2 2   13.78 dB

CORRELATION COEFF FOR LONG TERM VARIABILITY (CORRLT): 0.735910E+00

RELATIVE AVERAGE DELAY OF LOWER BEAM (DEL1) 329.5 nsec
RELATIVE AVERAGE DELAY OF UPPER BEAM (DEL2) 469.8 nsec

2*SIGMA DELAY SPREAD LOWER BEAM (TAU22): 131.7 nsec
2*SIGMA DELAY SPREAD UPPER BEAM (TAU23): 204.0 nsec

ESTIMATED MAXIMUM DELAY SPREAD LOWER BEAM (TEMP1): 313.4 nsec

Tx RADIO HORIXON ELEVATION ANGLE (THET) = 7.85556E-04 rad
Rx RADIO HORIXON ELEVATION ANGLE (THER) = 9.70620E-03 rad

Tx SITE AVERAGE TERRAIN ELEVATIONS (AVETX) = 884.36 m
Rx SITE AVERAGE TERRAIN ELEVATIONS (AVERX) = 1635.03 m

EFFECTIVE TRANSMITTER HEIGHT (HTE) = 602.36 m
EFFECTIVE RECEIVER HEIGHT (HRE) = 556.63 m

EFFECTIVE DISTANCE (DE): 181.18 km
MEDIAN CLIMATE CORRECTION FACTOR (VDE) = 3.543 dB

VARIABILITY DISTRIBUTION YO(QT,DE)

100 QT%	YO(QT,DE)
0.01	40.284
0.10	33.025
1.00	24.194
10.00	12.097
90.00	-9.804
99.00	-17.843
99.90	-23.628
99.99	-28.431

```
                          MODEM PARAMETERS
                          ----------------

RF BANDWIDTH CONSTRAINT (IBW):                              1
  0 = NO FILTER
  1 = 99% BANDWIDTH CONSTRAINT
  2 = FCC-19311 BANDWIDTH CONSTRAINT
  3 = USER-SPECIFIED TX AND RX FILTERS

BANDWIDTH (BW):                                             7.00 MHz
DATA RATE (DRATE):                                          6.3000 Mbits/sec

MODEM TYPE (MODPAT):                                        1
  1 = MD-918
  2 = AN/TRC-170 or DAR
  3 = User defined

NO. OF AFE TAPS (NTAP):                                     3
NO. OF FUTURE ISI CONTRIBUTORS CONSIDERED (LISI):           2
TAPWIDTH (TAPW):                  0.5000 (normalized)       0.15873 nsec


ERROR RATE THRESHOLD INDICATOR (NERT):                      0
  0 = ALL (1.0E-3 1.0E-4 1.0E-5)
  1 = 1.0E-3
  2 = 1.0E-4
  3 = 1.0E-5

                          INTERFERENCE PARAMETERS
                          -----------------------

  INTERFERENCE POWER DENSITY (JPOW):                    -1000.00 dBm/Hz
    (FOR NO INTERFERENCE, DENSITY IS -1000dBm/Hz)

  99% INTERFERENCE BANDWIDTH (JBW):                        10.50 MHz

  FREQUENCY SEPARATION BETWEEN
  SYSTEM AND INTERFERENCE (FJSEP):                         21.00 MHz

  INTERFERENCE SIGNAL MODULATION (MODSIG):                  1
  (0 = FDM/FM, 1 = QPSK)
```

4	2S/2F	4	-2.0	1.00E-03	9.95E-01	1.00E+00	1.00E+00	6.69E-02
4	2S/2F	4	-2.0	1.00E-04	1.00E+00	1.00E+00	1.00E+00	6.69E-02
4	2S/2F	4	-2.0	1.00E-05	1.00E+00	1.00E+00	1.00E+00	6.69E-02
2	2S	2	-2.0	1.00E-03	9.73E-01	1.00E+00	1.00E+00	8.75E-02
2	2S	2	-2.0	1.00E-04	9.96E-01	1.00E+00	1.00E+00	8.75E-02
2	2S	2	-2.0	1.00E-05	9.99E-01	1.00E+00	1.00E+00	8.75E-02
2	2S/2A	4	-2.0	1.00E-03	9.60E-01	1.00E+00	1.00E+00	5.64E-02
2	2S/2A	4	-2.0	1.00E-04	9.94E-01	1.00E+00	1.00E+00	5.64E-02
2	2S/2A	4	-2.0	1.00E-05	9.99E-01	1.00E+00	1.00E+00	5.64E-02
4	2S/2A/2F	8	-2.0	1.00E-03	9.91E-01	1.00E+00	1.00E+00	4.58E-02
4	2S/2A/2F	8	-2.0	1.00E-04	1.00E+00	1.00E+00	1.00E+00	4.58E-02
4	2S/2A/2F	8	-2.0	1.00E-05	1.00E+00	1.00E+00	1.00E+00	4.58E-02

<< MDTS>>

ANGLE DIVERSITY EIGENVALUES
LOWER BEAM (U(1-K3)) 8.525653E-01 9.707359E-02 8.827410E-03
UPPER BEAM (U(K2-K6)) 1.817663E-01 2.186429E-02 1.459400E-03

SPACE AND/OR FREQUENCY DIVERSITY EIGENVALUES (U(K7-K9))
8.51276E-01 1.10897E-01 9.93909E-03

<< BERCAL>>

MAIN BEAM DIV (ID)	DIV TYPE (XTYPE)	EXPLC DIV (ITOT)	Eb/No (SNR)	ERROR RATE THRESHOLD (P)	OUTAGE PROBABILITY (PFO)	FADE OUTAGE PER CALL-MINUTE (FCMIN)	BLOCK ERROR PROBABILITY (SUM2)	AVE BIT ERROR RATE (BERAV)
4	2S/2F	4	-4.0	1.00E-03	1.00E+00	1.00E+00	1.00E+00	1.29E-01
4	2S/2F	4	-4.0	1.00E-04	1.00E+00	1.00E+00	1.00E+00	1.29E-01
4	2S/2F	4	-4.0	1.00E-05	1.00E+00	1.00E+00	1.00E+00	1.29E-01
2	2S	2	-4.0	1.00E-03	9.99E-01	1.00E+00	1.00E+00	1.48E-01
2	2S	2	-4.0	1.00E-04	1.00E+00	1.00E+00	1.00E+00	1.48E-01
2	2S	2	-4.0	1.00E-05	1.00E+00	1.00E+00	1.00E+00	1.48E-01
2	2S/2A	4	-4.0	1.00E-03	9.98E-01	1.00E+00	1.00E+00	1.11E-01
2	2S/2A	4	-4.0	1.00E-04	1.00E+00	1.00E+00	1.00E+00	1.11E-01
2	2S/2A	4	-4.0	1.00E-05	1.00E+00	1.00E+00	1.00E+00	1.11E-01
4	2S/2A/2F	8	-4.0	1.00E-03	1.00E+00	1.00E+00	1.00E+00	1.01E-01
4	2S/2A/2F	8	-4.0	1.00E-04	1.00E+00	1.00E+00	1.00E+00	1.01E-01
4	2S/2A/2F	8	-4.0	1.00E-05	1.00E+00	1.00E+00	1.00E+00	1.01E-01

<< MDTS>>

ANGLE DIVERSITY EIGENVALUES
LOWER BEAM (U(1-K3)) 8.531458E-01 9.745348E-02 8.848793E-03
UPPER BEAM (U(K2-K6)) 1.819955E-01 2.190540E-02 1.466725E-03

SPACE AND/OR FREQUENCY DIVERSITY EIGENVALUES (U(K7-K9))
8.51851E-01 1.11414E-01 9.96180E-03

<< BERCAL>>

FOR002.DAT for RUN 1 (continued)

MAIN BEAM DIV (ID)	DIV TYPE (XTYPE)	EXPLC DIV (ITOT)	Eb/No (SNR)	ERROR RATE THRESHOLD (P)	OUTAGE PROBABILITY (PFO)	FADE OUTAGE PER CALL-MINUTE (FCMIN)	BLOCK ERROR PROBABILITY (SUM2)	AVE BIT ERROR RATE (BERAV)
4	2S/2F	4	-6.0	1.00E-03	1.00E+00	1.00E+00	1.00E+00	2.04E-01
4	2S/2F	4	-6.0	1.00E-04	1.00E+00	1.00E+00	1.00E+00	2.04E-01
4	2S/2F	4	-6.0	1.00E-05	1.00E+00	1.00E+00	1.00E+00	2.04E-01
2	2S	2	-6.0	1.00E-03	1.00E+00	1.00E+00	1.00E+00	2.18E-01
2	2S	2	-6.0	1.00E-04	1.00E+00	1.00E+00	1.00E+00	2.18E-01
2	2S	2	-6.0	1.00E-05	1.00E+00	1.00E+00	1.00E+00	2.18E-01
2	2S/2A	4	-6.0	1.00E-03	1.00E+00	1.00E+00	1.00E+00	1.81E-01
2	2S/2A	4	-6.0	1.00E-04	1.00E+00	1.00E+00	1.00E+00	1.81E-01
2	2S/2A	4	-6.0	1.00E-05	1.00E+00	1.00E+00	1.00E+00	1.81E-01
4	2S/2A/2F	8	-6.0	1.00E-03	1.00E+00	1.00E+00	1.00E+00	1.75E-01
4	2S/2A/2F	8	-6.0	1.00E-04	1.00E+00	1.00E+00	1.00E+00	1.75E-01
4	2S/2A/2F	8	-6.0	1.00E-05	1.00E+00	1.00E+00	1.00E+00	1.75E-01

<< PROUT>>

18 ITERATIONS

YEARLY FADE OUTAGE PROBABILITIES

AVERAGE FADE OUTAGE PROBABILITY

BER THRESHOLD (P)	2S/2F OUTAGE (BOUT)	2S OUTAGE (BOUT)	2S/2A OUTAGE (BOUT)	2S/2A/2F OUTAGE (BOUT)
1.00E-03	1.714827E-01	1.884333E-01	1.498745E-01	1.424578E-01
1.00E-04	2.120833E-01	2.301575E-01	1.892676E-01	1.812887E-01
1.00E-05	2.456336E-01	2.644017E-01	2.223893E-01	2.140621E-01

FADE OUTAGE PER CALL MINUTE

BER THRESHOLD (P)	2S/2F OUTAGE (FOUT)	2S OUTAGE (FOUT)	2S/2A OUTAGE (FOUT)	2S/2A/2F OUTAGE (FOUT)
1.00E-03	2.787410E-01	3.566694E-01	2.720131E-01	2.277542E-01
1.00E-04	3.297139E-01	4.121110E-01	3.252760E-01	2.766536E-01
1.00E-05	3.703055E-01	4.554965E-01	3.682041E-01	3.176190E-01

YEARLY BLOCK ERROR PROBABILITY

2S/2F ABE	2S ABE	2S/2A ABE	2S/2A/2F ABE
2.678583E-01	3.751102E-01	2.645297E-01	2.105809E-01

FOR002.DAT for RUN 1 (continued)

67ns SIMULATOR TAP VALUES

<< SIM>>

BEAM (IQ1, IQ2): 1 1

TAP NO. I	ATTEN (dB) (SNEG)
1	3.1
2	0.0
3	0.8
4	4.0
5	9.1
6	16.0
7	24.5
8	31.2
9	35.8
10	43.8
11	65.4
12	300.0
13	300.0
14	300.0
15	300.0
16	300.0

POWER CORRECTION FACTOR(dB) (PCF) = 4.6

BEAM (IQ1, IQ2): 2 2

TAP NO. I	ATTEN (dB) (SNEG)
1	13.2
2	6.2
3	1.7
4	0.0
5	0.4
6	2.0
7	4.4
8	8.0
9	13.4
10	22.1
11	44.6
12	300.0
13	300.0
14	300.0
15	300.0
16	300.0

POWER CORRECTION FACTOR(dB) (PCF) = 6.1

BEAM (I1CORR, I2CORR): 1 2 IC1, IC2 1 4

TAP NO. I	CORRELATION COEFFICIENT (TEMP1)
1	-6.61830E-01
2	-1.60368E-01

FOR002.DAT for RUN 1 (concluded)

3	1.26600E-01
4	2.21578E-01
5	2.68529E-01
6	2.31177E-01
7	-8.76071E-02
8	-7.12933E-01
9	-9.56022E-01
10	-9.90172E-01
11	-9.98205E-01

TROPO COMPLETED: 15-NOV-83 22:17:19

SUMPAG.OUT for RUN 1

```
TROPOSCATTER PATH CALCULATIONS      15-NOV-83  22:14:57

   Tx Site - Rx Site
   RUN 1: TROPO - MD-918                            Page  1

                                Tx Site        Rx Site

Site Elevations (AMSL):       4822.7 ft      7135.5 ft
Horizon T.O. Angles:            0.05 deg       0.56 deg
Antenna heights (AGL):          55.0 ft        55.0 ft
Antenna diameters:              88.6 ft        88.6 ft

Climate Type:   MIL-HDBK-417 CT

Freq.:     0.9 GHz ; Pathlength:  178.3 smi
Scat. ang.:  2.54 deg
Path asymmetry  s =  0.87deg /  1.67deg  =  0.5247

Transmit power:  100.0 W  ;  BW:    7.0 MHz

Line losses:  3.00 dB.   Atm. Abs. loss:  1.30dB

Beam   2-sigma del.spr.  Pathloss   RSL   (Reference values)

  1      131.7nsec       229.0 dB   -89.9 dBm
  2      204.0nsec       234.6 dB   -95.5 dBm

Correl.12: 0.0421   Receiver elevation angle diversity correlation
                    (El. Squint =   1.13 deg )
       13: 0.0019   Divergent paths space diversity correlation
                    ( Rx Horz.Ant.Spac.= 200.0 ft  )
Min freq. separation required for freq div. [MHz] =      9.951

Correlation or coherence bandwith [MHz] =      2.951

   TROPOSCATTER PATH LOSS LONG TERM DISTRIBUTION

                 50%        99%       99.99%
Path Loss(dB)   231.32     255.05     271.15
RSL(dBm)        -92.26    -115.99    -132.09

Standard deviation of troposcatter path loss distribution:  10.509dB

Effective path distance:    181.18km
```

SUMPAG.OUT for RUN 1 (continued)

TROPOSCATTER PATH CALCULATIONS

Tx Site - Rx Site
RUN 1: TROPO - MD-918 Page 2

Modem Type: MD-918

Average Yearly Fade Outage Probability

DIVERSITY CONFIGURATION	2S/2F	2S	2S/2A	2S/2A/2F
@ 1.00E-04 BER	2.12E-01	2.30E-01	1.89E-01	1.81E-01

Yearly Fade Outage Per Call Minute Probability (YFOP)

DIVERSITY CONFIGURATION	2S/2F	2S	2S/2A	2S/2A/2F
YFOP @ 1.00E-04 BER	3.30E-01	4.12E-01	3.25E-01	2.77E-01

SUMPAG.OUT for RUN 1 (concluded)

TROPOSCATTER PATH CALCULATIONS

```
    Tx Site - Rx Site
    RUN 1: TROPO - MD-918                          Page  3

Auxiliary data

LUNITS= 8 (smi -ft  -deg -GHz )

Desired receive beam correlations:
           11: prof
           12: prof
           13: prof
           22: prof

Theoretical reference path loss :     229.19 dB

Horizon dist.&elev.(AMSL):  88.0 smi 9127.5 ft        33.3 smi 9453.5 ft

Eff. earth radius factor= 1.33 Spectrum slope= 5.00

Integration resolution params. ERR=  0.001000 NACCU=   40

Height of top of common volume HHIGH =      20645.8 ft
Height of bottom of common volume HCOM =    12226.1 ft
No. of cells in integration = 16704
```

Example 2

This example illustrates the format of the input file when mixed troposcatter-diffraction is specified (PTYPE = 11 here). We also use MODPAT = 1 to request performance calculations for the MD-918 modem under mixed propagation conditions. The detailed output file FOR002.DAT is similar to that for example 1 except that the MD-918 performance output is also given for diffraction path SNR's of +6 dB, 0 dB and -6 dB. The short-term modem performance is calculated for diffraction path SNR's between +15 dB and -15 dB in 3 dB increments. Long term modem performance is then calculated by weighting the short-term modem performance for all eleven diffraction path SNR's according to the long-term distributions of the diffraction and troposcatter path SNR's.

The input file TROPO.DAT, and the output files FOR002.DAT and SUMPAG.OUT are listed next. Since the FOR002.DAT output file is very lengthy, only the outage probability table for SNR = 28.0 and DSNR = 6.0 is given.

TROPO.DAT for RUN 2

```
------------------------- Input File Version 1.0 --------------------------
START -- * -- * -- * -- * -- * -- * -- * -- * -- * -- * -- * -- * -- * --
* LINK NAME from transmit site to receive site (40 character maximum)
RUN 2: TROPO/DIFFRACTION - MD-918
* MODPAT:        0 = Propagation only,
*                1 = Propagation + MD-918 -- Default
*                2 = Propagation + AN/TRC-170
*                3 = Propagation + user-defined modem.
1
* ICLIME:  Climate class; 0 = NBS (default), 1 = MIL-HDBK-417, 2 = New
1
* CLIMAT:  Climate code (See user's manual sec. 3.2; 4 character maximum)
CT
* GPF:  Frequency Correction Factor (default = 1.0)
1.0
* YMIN,DEMIN:    YO(90), DE at minima in kilometers
*                (used only when ICLIME=2)
0  0
* YZERO,Y900:    YO(90) at DE = 0, YO(90) at DE .ge. 900 kilometers
*                (used only when ICLIME=2)
0  0
* DISTU:  Distance units (SMI/KM/NMI); 4 character maximum
SMI
* HDU:  Height, elevation, diameter units (FT/M); 4 character maximum
FT
* ANGU:  Angle units (DEG/MRAD); 4 character maximum
DEG
* FREQU:  Frequency units (GHZ/MHZ); 4 character maximum
GHZ
* POWERU:  Transmit power units (W/dBm); 4 character maximum
DBM
* TXPOW:  Transmit power (defaults = 70 dBm, 10000 W)
50
* F:  Frequency (See user's manual sec 3.2 for limitations) (GHZ/MHZ)
0.875
* SP, NFIG:  Service Probability, Noise Figure (defaults = 0.95, 4dB)
.95  4.0
* TLL,RLL:  Transmitter, receiver line losses in dB (defaults = 0, 0)
1.5  1.5
* D:  Great circle distance at sea level between transmitter and receiver
*     (SMI/KM/NMI)
178.3
* HTO, HRO:  Transmitter, receiver site elevations above sea level (FT/M)
4822.82  7135.81
* HT,HR:  Transmitter, receiver antenna heights above ground (FT/M)
55  55
* PTYPE:  0 or 10 = Troposcatter; 1 or 11 = Mixed Troposcatter-Diffraction
*         PTYPE = 10 or 11 yields no correlation matrix in SUMPAG.OUT
11
TROPOSCATTER-ONLY SECTION -- * -- * -- Data for PTYPE = 1 or 10 * -- * -- * --
* ITOFF:  0 = input THET, THER (default), 2 = compute THET, THER
2
* THET, THER:  Transmitter, receiver horizon elevation angles (DEG/MRAD)
.06  .60
* DLT, DLR:  Transmitter, receiver distances to horizon (KM/SMI/NMI)
88.0  33.3
* HLT, HLR:  Transmitter, receiver horizon elevations above sea level (FT/M)
```

TROPO.DAT for RUN 2 (continued)

```
9128  9454
* NTERR:  Set flag:      0 = HTE, HRE are input,
*                        1 = use AVETX, AVERX
*                        2 = use terrain elevations (HI) to calculate HTE, HRE
2
* HTE, HRE:  Effective transmitter, receiver antenna heights
*            above average terrain elevations (FT/M)
0  0
* AVETX, AVERX:  Transmitter, receiver average foreground terrain elevations
*                above sea level (FT/M)
797.27  1619.79
* NP1, NP2:  Transmitter, receiver number of terrain elevations.
*            (Equivalent to NPM(1), NPM(2) in source code.) (defaults = 1,0)
9  9
* HI(1:NP1+NP2):  Terrain elevations beginning with transmit site elevation
*                 and ending with receive site elevation (FT/M)
4822.82  3535  3500  3485  3200  4160  4500  5000  9128
9454  5800  5700  5600  5650  5500  5400  5500  7135.81
DIFFRACTION SECTION -- * -- * -- * -- Data for PTYPE = 1 or 11 * -- * -- * --
* NOBS:  Number of diffraction obstacles;  maximum = 3 (default = 1)
2
* HL(1:NOBS):  Obstacle elevations above sea level beginning with transmit
*              horizon HLT and ending with receive horizon HLR (FT/M)
9128  9454
* DL(1:NOBS):  Great circle obstacle distances from transmitter (SMI/NMI/KM)
88.0  145.0
* DS(1:NOBS):  Effective horizontal obstacle extents (SMI/NMI/KM)
.04  .04
* NTERR:  Set flag:      0 = HTE, HRE ,HLEF are given next
*                        1 = use AVETX, AVERX, HLAV
*                        2 = use terrain elevations (HI) to calculate HTE, HRE
2
* HTE, HRE:  Effective transmitter, receiver antenna heights above
*            average terrain elevations.  Used only for NTERR = 0. (FT/M)
0  0
* HLEF(1:NOBS):  Effective diffraction obstacle heights above average terrain
*                elevation.  Used only for NTERR = 0. (FT/M)
0  0
* AVETX, AVERX:  Transmitter, receiver average terrain elevations above
*                sea level.  Used only for NTERR = 1. (FT/M)
3400  7135
* HLAV(1:NOBS):  Average terrain elevation above sea level at each
*                diffraction point.  Used only for NTERR = 1. (FT/M)
7800  8500
* NPM(1:NOBS+1):  Number of terrain elevations between each pair of diffraction
*                 obstacles. (Tx and Rx are end points.) (default = 1,0,0,0)
9  9  9
* HI(1:NPM(1) + ... + NPM(NOBS+1)):  Terrain elevation data beginning with
*       transmit site elevation and ending with receive site elevation (FT/M)
4822.82  3535  3500  3485  3200  4160  4500  5000  9128
9128  7250  7100  7250  7500  8000  8150  8000  9454
9454  5800  5700  5600  5650  5500  5400  5500  7135.81
DIVERSITY DATA INPUT SECTION -- * -- * -- * -- * -- * -- * -- * -- * -- * --
* DIVTYP:  Diversity Type (default = 0)
*       0 = 2S      2S/2F        2S/2A    2S/2A/2F
*       1 = 2A      2F           2F/2A
*       2 = 2S/2P   2S/2P/2A
*     S = Space  F = Frequency  A = Angle  P = Polarization
```

TROPO.DAT for RUN 2 (continued)

```
 TDIAM:  Transmitter antenna aperture diameter (AT(1)) (FT/M)
8 58
 RDIAM:  Receiver antenna aperture diameter (AR(1)) (FT/M)
8 58
 TELH   Transmitter antenna beam elevation above horizon (PSITEO(1)).  Input
        an angle 4000 or greater to have TELH calculated.  (DEG/MRAD)
000
 RELH   Receiver antenna beam elevation above horizon (PSIREO(1)).  Input
        an angle 4000 or greater to have RELH calculated.  (DEG/MRAD)
27
 PHDIV  Angle between upper and lower beams (Default = Beamwidth) (DEG/MRAD)
 0
 TFLAG, TSEP   TFLAG = Transmitter antenna spacing indicator
               (TFLAG must be 0 for this version of TROPO.)
               TSEP = Transmitter antenna separation (FT/M)
  200
 RFLAG, RSEP   RFLAG = Receiver antenna spacing indicator
               (RFLAG must be 0 for this version of TROPO.)
               RSEP = Receiver antenna separation (FT/M)
  200
ROPAGATION DATA INPUT SECTION -- * -- * -- * -- * -- * -- * -- * -- * -- * --
 SEAN   Refractivity at sea level (default = 0)

 ERFAC  Effective Earth Radius Factor, K.  Recalculated if SEAN > 0.
        (default = 1.33)
 33
 SCPARM  Wavenumber Spectrum Slope Parameter M for atmospheric turbulence.
         Reset to 5 if Frequency < 1GHz.  (default = 3.66)
 66
 NACCU, ERR  Integration accuracy (truncation point) and resolution.
             (defaults = 40, 0.001)
0   001
 TAPOUT  Enter T to have simulator tap values output in FOR002.DAT (default),
         enter F to suppress the calculations and output.

 SPE, MLAST  Simulator tap spacing in nanoseconds and
             number of taps (defaults = 67 nsec, 16)
7  16
 KPROF  Number of CN2 profile samples.  Maximum = NPROF  (See TROPAR.INC)

 HLOW,DELH:  Lowest height above sea level at which CN2 is specified (FT/M),
             Spacing of CN2 samples (FT/M)
  0
 CN2(KPROF):  The atmospheric structure constant height profile samples (FT/M)

DEM INPUT SECTION -- * -- * -- * -- Data for MODPAT > 0 * -- * -- * -- * -- *
 IBW   Bandwidth constraint indicator (default = 0)
       0 = No filter, 1 = 99%, 2 = FCC-19311, 3 = user specified

 IFILTX,IFILRX:  Transmit, receive filter impulse response (For IBW = 3 only):
               0 = MD-918 filter for receiver or transmitter
               1 = AN/TRC-170 filter for transmitter (not used for receiver)
               2 = AN/TRC-170 filter for receiver (not used for transmitter)
  0
 FCTX,FCRX:  Transmitter, receiver 3dB cut-off frequencies (For IBW = 3 only)
             (MHZ only)
  0
```

TROPO.DAT for RUN 2 (continued)

```
* NPOLTX,NPOLRX:  Number of transmitter, receiver poles of Butterworth filter
*                 (For IBW = 3 only)
0  0
* BW:  Bandwidth, (default = 7.0 MHz)  (MHZ only)
7.0
* DRATE:  Data rate (bits/second)  (default = 6.6E6 bits/second)
6.3E6
* NERT:  Bit error rate threshold indicator:
*        0 = all, 1 = 1.0E-3, 2 = 1.0E-4 (default), 3 = 1.0E-5
2
MD-918 MODEM INPUT SECTION -- * -- * -- * -- Data for MODPAT = 1 * -- * -- * --
* TAPW:  Normalized tap width.  Range = 0.25 through 1.0.  (default = .5)
.5
* LISI:  Number of future ISI contributors considered  (default = 2)
2
AN/TRC-170 MODEM INPUT SECTION -- * -- * -- Data for MODPAT = 2 * -- * -- * --
* TRCTYP:  0 = single frequency, DAR modem;
*          1 = two frequencies, AN/TRC-170 modem (default)
1.0
INTERFERENCE PARAMETER INPUT SECTION -- * -- * -- * -- * -- * -- * -- * --
* JPOW:  Interference Power Density (default = -1000dBm/Hz for no interference)
-1000.
* JBW:  99% Interference Bandwidth (default = Bandwidth BW) (MHZ only)
10.5
* FJSEP:  Frequency separation between the interference signal and desired
*         signal (default = larger of BW and JBW) (MHZ only):
*               0. = co-channel interference
*               > BW and JBW = adjacent channel interference
21.0
* MANG:  Number of interferer azimuth, elevation pairs (default = 1)
5
* (XANG(I), ELANG(I),I=1,MANG):  Interferer azimuth, elevation angle (above
*       horizon) pairs.  (default = 0,0)  (DEG/MRAD)
.05  0  32.  0  8.  0  2.  0  .05 0
* MODSIG:  Interfering signal modulation format; 0 = FDM/FM, 1 = QPSK (default)
1
USER-SUPPLIED DIVERSITY INPUT SECTION -- * -- * -- * -- * -- * -- * -- * --
* NT, NR:  Number of transmit and receive ports;  Maximums = NTMX, NRMX
1  2
* AT(NT):  Transmitter antenna aperture diameter (FT/M)
28
* AR(NR):  Receiver antenna aperture diameter (FT/M)
2*30
* PSITEO(NT):  Transmitter beam elevation above horizon (DEG/MRAD)
4000
* PSIREO(NR):  Receiver beam elevation above horizon (DEG/MRAD)
2*.33966
* PSITAO(NT):  Transmitter beam azimuth (DEG/MRAD)
0
* PSIRAO(NR):  Receiver beam azimuth (DEG/MRAD)
0.  0.
* IPOLT(NT):  Transmitter polarizations (DEG/MRAD)
0
* IPOLR(NR):  Receiver polarizations (DEG/MRAD)
0  0
* ((IBR(I,J),J=I,NR),I=1,NR):  Beams and cross-beams at receiver.
*       Enter:  0 = correlation between receivers I and J is not desired
*               1 = only power (correlation) calculations are desired
```

FOR002.DAT for RUN 2 (continued)

```
                         FILTER DATA
                         -----------
                                                            <<  BUTFIL>>

                    TRANSMITTER              RECEIVER
Filter type             0      (IFILTX)         0      (IFILRX)
Poles                   2      (NPOLTX)         4      (NPOLRX)
Cut-off freq (MHz)      3.10   (FCUT1)          3.50   (FCUT2)

    TRANSMISSION BANDWIDTH (MHz) (FCUT) =   7.0000

    FILTER TYPE REFERS TO THE RECTANGULAR SECTION
     = 0:  FULL SYMBOL INTERVAL DURATION
     = 1:  HALF SYMBOL INTERVAL DURATION
     = 2:  NO RECTANGULAR SECTION

    PEAK-TO-AVERAGE POWER RATIO (dB) (PEAKAV) =  1.2519
```

FOR002.DAT for RUN 2 (continued)

DIFFRACTION PATH LOSS DISTRIBUTION (50% SERV. PROB.)

<< AVAIL>>

100 QT % (QT)	LOSS(QT) (PLOSS)	V(QT) (V1)	Y(QT) (Y)	SIGMA (SIG)
0.010	207.695	17.69	17.69	7.09
0.100	210.559	14.82	14.82	6.25
1.000	214.120	11.26	11.26	5.29
10.000	218.427	6.95	6.95	4.30
20.000	220.404	4.98	4.98	3.96
50.000	225.381	0.00	0.00	3.57
80.000	227.905	-2.52	-2.52	3.67
90.000	229.041	-3.66	-3.66	3.79
99.000	231.457	-6.08	-6.08	4.14
99.900	233.120	-7.74	-7.74	4.46
99.990	234.508	-9.13	-9.13	4.77

<< DIFSNR>>

PATH LOSS, RSL AND SNR DISTRIBUTIONS FOR DIFFRACTION PATH

SERVICE PROBABILITY (SP) = 0.950

MEDIAN PATH LOSS (dB) (DLOSS(6)) = 231.268

MEDIAN AND AVERAGE Eb/No (dB) (ASNR) = 8.384
STANDARD DEVIATION (dB) (DSTSNR) = 2.98

PERCENTILE NOT EXCEEDED (QT)	PATH LOSS (dB) (DLOSS)	RSL (dBm) (RSL)	Eb/No (dB) (SNR)
0.01	219.39	-81.75	20.26
0.10	220.88	-83.23	18.78
1.00	222.84	-85.20	16.81
10.00	225.53	-87.89	14.12
20.00	226.94	-89.30	12.71
50.00	231.27	-93.62	8.38
80.00	233.97	-96.32	5.69
90.00	235.29	-97.64	4.36
99.00	238.29	-100.65	1.36
99.90	240.48	-102.84	-0.83
99.99	242.37	-104.73	-2.72

RATIO OF DIFFRACTION SIGNAL OF UPPER BEAM TO LOWER BEAM (dB) (DUPOWL): -12.19806

FOR002.DAT for RUN 2 (continued)

DIFFRACTION PATH CALCULATIONS

```
                                                            <<    MDIF>>
EDGE NO. (K) = 1
     DIFFRACTION ANGLE (deg) (PHI) =     1.25
     RADIUS OF CURVATURE IN METERS (RC) =   2946.42
     DIFFRACTION LOSS IN dB (AV1): 0.4323E+02 OR (AV2) 0.4213E+02

EDGE NO. (K) = 2
     DIFFRACTION ANGLE (deg) (PHI) =     1.29
     RADIUS OF CURVATURE IN METERS (RC) =   2855.13
     DIFFRACTION LOSS IN dB (AV1): 0.4042E+02 OR (AV2) 0.4150E+02


FREE-SPACE LOSS (dB) (LF) =  140.44
DIFFRACTION LOSS (dB) (LDIF) =    83.64

LONG TERM DIFFRACTION PATH LOSS REF. VALUE (dB) (LB) =  224.08


REFERENCE DELAY (D1E3) =      0.957 msec
DIFFRACTION PATH RELATIVE DELAY (DELE9) =   137.56 nsec
```

FOR002.DAT for RUN 2 (continued)

YEARLY DISTRIBUTION OF SHORT-TERM MEAN Eb/No

SERVICE PROBABILITY (SP) = 0.950

MEDIAN OF SHORT-TERM MEAN Eb/No (ASNR) 1.1341E+01
STANDARD DEVIATION (STSNR) 1.0509E+01
MEDIAN PATHLOSS (PMED) 231.33

PERCENTILE (NOT EXCEEDED) (TEMP1)	PATH LOSS (dB) (TLOSS)	RSL (dBm) (RSL)	MEAN Eb/No (SNR)
0.01	208.922	-69.861	33.745
0.10	212.188	-73.127	30.480
1.00	216.275	-77.214	26.392
10.00	222.424	-83.363	20.244
50.00	231.327	-92.266	11.341
90.00	243.372	-104.311	-0.704
99.00	255.059	-115.998	-12.391
99.90	263.800	-124.739	-21.132
99.99	271.156	-132.095	-28.488

FOR002.DAT for RUN 2 (continued)

```
TROPOSCATTER PROPAGATION OUTPUT PARAMETERS:  SECTION 1
------------------------------------------------------

                                                                  <<   POWER>>

ATMOSPHERIC ABSORPTION LOSS (AA):                         1.304 dB
TRANSMIT BEAMWIDTH (BWT):                                 0.9031 deg
RECEIVE BEAMWIDTH  (BWR):                                 0.9031 deg

NUMBER OF INTEGRATION CELLS (ITER):                   16704

LONG TERM REFERENCE TROPOSCATTER PATH LOSS,
NO CLIMATE CORRECTION

REFERENCE PATH LOSS ON LOWER BEAM (TEMP1):              228.98 dB
REFERENCE PATH LOSS ON UPPER BEAM (TEMP2):              234.59 dB
CORRELATION COEFFICIENT BETWEEN LOWER AND
UPPER BEAM (RH1):                                         0.0422

APERTURE-TO-MEDIUM COUPLING LOSS (CPL): BEAM 1 1         11.39 dB
APERTURE-TO-MEDIUM COUPLING LOSS (CPL): BEAM 2 2         13.79 dB

CORRELATION COEFF FOR LONG TERM VARIABILITY (CORRLT): 0.735932E+00

RELATIVE AVERAGE DELAY OF LOWER BEAM (DEL1)             329.7 nsec
RELATIVE AVERAGE DELAY OF UPPER BEAM (DEL2)             470.0 nsec

2*SIGMA DELAY SPREAD LOWER BEAM (TAU22):                131.7 nsec
2*SIGMA DELAY SPREAD UPPER BEAM (TAU23):                204.1 nsec

ESTIMATED MAXIMUM DELAY SPREAD LOWER BEAM (TEMP1):      313.5 nsec

Tx RADIO HORIXON ELEVATION ANGLE (THET) =                 7.89534E-04 rad
Rx RADIO HORIXON ELEVATION ANGLE (THER) =                 9.71584E-03 rad

Tx SITE AVERAGE TERRAIN ELEVATIONS (AVETX) =            884.36 m
Rx SITE AVERAGE TERRAIN ELEVATIONS (AVERX) =           1635.03 m

EFFECTIVE TRANSMITTER HEIGHT (HTE) =                    602.36 m
EFFECTIVE RECEIVER HEIGHT (HRE) =                       556.63 m

EFFECTIVE DISTANCE (DE):                                181.18 km
MEDIAN CLIMATE CORRECTION FACTOR (VDE) =                  3.543 dB

  VARIABILITY DISTRIBUTION YO(QT,DE)

      100 QT%          YO(QT,DE)
        0.01             40.284
        0.10             33.025
        1.00             24.194
       10.00             12.097
       90.00             -9.804
       99.00            -17.843
       99.90            -23.628
       99.99            -28.431
```

FOR002.DAT for RUN 2 (continued)

```
                         MODEM PARAMETERS
                         ----------------

RF BANDWIDTH CONSTRAINT (IBW):                           1
  0 = NO FILTER
  1 = 99% BANDWIDTH CONSTRAINT
  2 = FCC-19311 BANDWIDTH CONSTRAINT
  3 = USER-SPECIFIED TX AND RX FILTERS

BANDWIDTH (BW):                                          7.00 MHz
DATA RATE (DRATE):                                       6.3000 Mbits/sec

MODEM TYPE (MODPAT):                                     1
  1 = MD-918
  2 = AN/TRC-170 or DAR
  3 = User defined

NO. OF AFE TAPS (NTAP):                                  3
NO. OF FUTURE ISI CONTRIBUTORS CONSIDERED (LISI):        2
TAPWIDTH (TAPW):                 0.5000 (normalized)     0.15873 nsec


ERROR RATE THRESHOLD INDICATOR (NERT):                   2
  0 = ALL (1.0E-3 1.0E-4 1.0E-5)
  1 = 1.0E-3
  2 = 1.0E-4
  3 = 1.0E-5

                         INTERFERENCE PARAMETERS
                         -----------------------

  INTERFERENCE POWER DENSITY (JPOW):                 -1000.00 dBm/Hz
    (FOR NO INTERFERENCE, DENSITY IS -1000dBm/Hz)

  99% INTERFERENCE BANDWIDTH (JBW):                     10.50 MHz

  FREQUENCY SEPARATION BETWEEN
  SYSTEM AND INTERFERENCE (FJSEP):                      21.00 MHz

  INTERFERENCE SIGNAL MODULATION (MODSIG):               1
  (0 = FDM/FM, 1 = QPSK)
```

FOR002.DAT for RUN 2 (continued)

TRANSMITTER OFFSETS (RELATIVE LOCATION)

	HORIZONTAL (UTH)	VERTICAL (UTV)	LONGITUDINAL (UTL)
PORT 1	0.00 ft	55.00 ft	0.00 ft

RECEIVER OFFSETS (RELATIVE LOCATION)

	HORIZONTAL (URH)	VERTICAL (URV)	LONGITUDINAL (URL)
PORT 1	100.00 ft	55.00 ft	0.00 ft
PORT 2	100.00 ft	55.00 ft	0.00 ft
PORT 3	-100.00 ft	55.00 ft	0.00 ft
PORT 4	-100.00 ft	55.00 ft	0.00 ft

EFFECTIVE EARTH RADIUS FACTOR K (ERFAC): 1.3300
WAVENUMBER SPECTRUM SLOPE PARAMETER M (SCPARM): 5.00
PARAMETER FOR TERMINATION OF NUMERICAL INTEGRATION
(NACCU) 40
INTEGRATION RESOLUTION (ERR): 0.0010

FOR002.DAT for RUN 2 (continued)

```
ANGLE BETWEEN UPPER AND LOWER BEAM (PHDIV):          1.1289 deg

BEAM AND CROSS-CORRELATION BEAM INDICATORS
  0 = NO CALCULATION
  1 = POWER (CORRELATION) ONLY
  2 = DELAY (CROSS) POWER SPECTRUM
         IBR(1,1)  =  2
         IBR(1,2)  =  2
         IBR(1,3)  =  2
         IBR(1,4)  =  0
         IBR(2,2)  =  2
         IBR(2,3)  =  0
         IBR(2,4)  =  0
         IBR(3,3)  =  0
         IBR(3,4)  =  0
         IBR(4,4)  =  0
```

```
EVENLY SPACED TERRAIN ELEVATION ABOVE SEA LEVEL DATA IN ft
  HI      1:  9          10: 18          19: 27
        4822.82         9128.00         9454.00
        3535.00         7250.00         5800.00
        3500.00         7100.00         5700.00
        3485.00         7250.00         5600.00
        3200.00         7500.00         5650.00
        4160.00         8000.00         5500.00
        4500.00         8150.00         5400.00
        5000.00         8000.00         5500.00
        9128.00         9454.00         7135.81

DIVERSITY TYPE (DIVTYP):                                 0
  0 = DIVERSITY OPTIONS:
      2S/2F, 2S, 2S/2A, 2S/2A/2F
  1 = DIVERSITY OPTIONS:
      2A, 2F, 2F/2A
  2 = DIVERSITY OPTIONS:
      2S/2P, 2S/2P/2A
  S = SPACE F = FREQUENCY A = ANGLE P = POLARIZATION

NUMBER OF TRANSMIT PORTS (NT):                           1
NUMBER OF RECEIVE PORTS  (NR):                           4

TRANSMIT ANTENNA DIAMETER (AT): PORT 1                 88.58 ft

RECEIVE ANTENNA DIAMETER (AR):  PORT 1                 88.58 ft
RECEIVE ANTENNA DIAMETER (AR):  PORT 2                 88.58 ft
RECEIVE ANTENNA DIAMETER (AR):  PORT 3                 88.58 ft
RECEIVE ANTENNA DIAMETER (AR):  PORT 4                 88.58 ft

ANTENNA BORESIGHT ELEVATION ABOVE REFERENCE HORIZON
  TRANSMIT (PSITEO): PORT 1                              0.2258 deg  --> Angle calculated

  RECEIVE  (PSIREO): PORT 1                              0.2258 deg  --> Angle calculated
  RECEIVE  (PSIREO): PORT 2                              1.3547 deg  --> Angle calculated
  RECEIVE  (PSIREO): PORT 3                              0.2258 deg  --> Angle calculated
  RECEIVE  (PSIREO): PORT 4                              1.3547 deg  --> Angle calculated

ANTENNA BORESIGHT AZIMUTH, DEFINES
THE ANGLE TO THE GREAT-CIRCLE PLANE
 POSITIVE COUNTER-CLOCKWISE FOR TRANSMIT
 POSITIVE CLOCKWISE FOR RECEIVE
  TRANSMIT (PSITAO): PORT 1                              0.0000 deg

  RECEIVE  (PSIRAO): PORT 1                              0.0000 deg
  RECEIVE  (PSIRAO): PORT 2                              0.0000 deg
  RECEIVE  (PSIRAO): PORT 3                              0.0000 deg
  RECEIVE  (PSIRAO): PORT 4                              0.0000 deg

POLARIZATIONS
  TRANSMIT (IPOLT): PORT 1                               0

  RECEIVE  (IPOLR): PORT 1                               0
  RECEIVE  (IPOLR): PORT 2                               0
  RECEIVE  (IPOLR): PORT 3                               0
  RECEIVE  (IPOLR): PORT 4                               0
```

```
TRANSMIT POWER (PXMIT):                                    50.00 dBm
TRANSMIT POWER (WLT):                                     100.00 W

FREQUENCY (F):                                              0.87 GHz

SERVICE PROBABILITY (SP):                                   0.950
NOISE FIGURE (NFIG):                                        4.00 dB

TRANSMITTER LINE LOSS (TLL):                                1.50 dB
RECEIVER LINE LOSS (RLL):                                   1.50 dB

TERMINAL DISTANCE (D):                                    178.30 smi

SITE ELEVATION ABOVE SEA LEVEL:
  TRANSMITTER (HTO)                                      4822.82 ft
  RECEIVER    (HRO)                                      7135.81 ft

ANTENNA HEIGHT ABOVE GROUND:
  TRANSMITTER (HT)                                         55.00 ft
  RECEIVER    (HR)                                         55.00 ft

ANTENNA HEIGHTS ABOVE SEA LEVEL:
  TX HTS=HTO+HT                                          4877.82 ft
  RX HRS=HRO+HR                                          7190.81 ft

PATH CALCULATION INDICATOR (PTYPE):                        1
  0 = TROPOSCATTER ONLY
  1 = MIXED TROPOSCATTER-DIFFRACTION OR DIFFRACTION ONLY
      PTYPE = 10 OR 11 EQUIVALENT TO PTYPE = 0 OR 1
      WITH POWER VS DELAY PROFILE OUTPUT SUPPRESSED

NUMBER OF DIFFRACTION OBSTACLES (NOBS):                    2

DIFFRACTION OBSTACLE DATA:
  OBSTACLE  ELEVATION      GREAT CIRCLE     EFFECTIVE HORIZONTAL
              ABOVE       DISTANCE FROM       EXTENT ALONG
            SEA LEVEL      TRANSMITTER      GREAT CIRCLE PATH
              (HL)            (DL)                (DS)
      1     9128.00 ft      88.00 smi           0.040 smi
      2     9454.00 ft     145.00 smi           0.040 smi

HTE,HRE DATA INDICATOR (NTERR):                            2
  0 = USER-SUPPLIED
  1 = AVETX,AVERX DATA
      PLUS HLAV DATA
  2 = TERRAIN ELEVATION DATA
      NPM AND HI

NO  OF TERRAIN ELEVATION DATA POINTS BETWEEN
TX AND 1ST OBSTACLE, BETWEEN OBSTACLES, AND
BETWEEN LAST OBSTACLE AND RX
          I  NPM(I)
          1     9
          2     9
          3     9
```

FOR002.DAT for RUN 2 (continued)

26 = nmi ft deg MHz

FOR002.DAT for RUN 2

```
*** INPUT PARAMETERS *** 15-NOV-83  22:17:20
                                                                  << OUTDAT>>

                              PATH PARAMETERS
                              ---------------

LINK NAME (LNAME): RUN 2: TROPO/DIFFRACTION - MD-918

PATH/MODEM INDICATOR (MODPAT):        1
  0 = Path only
  1 = Path + MD-918 modem
  2 = Path + AN/TRC-170 or DAR modem
  3 = Path + user defined modem

CLIMATE CLASS (ICLIME):               1
  0 = NBS TN101 CLIMATE
  1 = MIL-HDBK-417 CLIMATE
  2 = NEW USER-SUPPLIED CLIMATE

CLIMATE (CLIMAT):      CT

 NBS CLIMATES:
   CT   = CONTINENTAL TEMPERATE
   MTL  = MARITIME TEMPERATE OVERLAND
   MTS  = MARITIME TEMPERATE OVERSEA
   MSL  = MARITIME SUBTROPICAL OVERLAND
   CT2  = CONTINENTAL TEMPERATE TIME BLOCK 2
   DS   = DESERT, SAHARA
   EQU  = EQUATORIAL
   CS   = CONTINENTAL SUBTROPIC
   CTD  = MIXED CLIMATES - CT AND DS
   MTLD = MIXED CLIMATES - MTL AND DS

 MIL-HDBK-417 CLIMATES:
   CT   = CONTINENTAL TEMPERATE
   MTL  = MARITIME TEMPERATE OVERLAND
   MTS  = MARITIME TEMPERATE OVERSEA
   MS   = MARITIME SUBTROPICAL
   DS   = DESERT, SAHARA
   EQU  = EQUATORIAL
   CS   = CONTINENTAL SUBTROPICAL
   MED  = MEDITERRANEAN
   POL  = POLAR

I/O UNITS INDICATOR (LUNITS):   8 = smi   ft    deg   GHz
   0 = smi ft  mrad GHz
   1 = km  m   mrad GHz
   2 = nmi ft  mrad GHz
   8 = smi ft  deg  GHz
   9 = km  m   deg  GHz
  10 = nmi ft  deg  GHz
  16 = smi ft  mrad MHz
  17 = km  m   mrad MHz
  18 = nmi ft  mrad MHz
  24 = smi ft  deg  MHz
  25 = km  m   deg  MHz
```

***** Ignoring PSITEO and PSIREO input. Calculating angles.

TROPO.DAT for RUN 2 (concluded)

```
*              2 = power (correlation) per unit delay calculations are desired
2  2  2
* UTH(NT):  Transmitter horizontal offsets (FT/M)
0
* UTV(NT):  Transmitter vertical offsets (FT/M)
0
* UTL(NT):  Transmitter longitudinal offsets (FT/M)
0
* URH(NR):  Receiver horizontal offsets (FT/M)
0  0
* URV(NR):  Receiver vertical offsets (FT/M)
0  0
* URL(NR):  Receiver longitudinal offsets (FT/M)
0  0
END
```

FOR002.DAT for RUN 2 (continued)

```
MD-918 MODEM OUTPUT PARAMETERS:  SECTION 2
------------------------------------------

                                                                <<    MDTS>>

NUMBER OF CHIPS PER BIT (KGAIN):                         1

CHIP SEQUENCE (ASEQ)
   1                 1

                                                                <<   BOTAC>>

NO. OF AFE TAPS (K1) AND TAP WIDTH IN T UNITS (TAPW) =        3     0.50

                                                                <<    MDTS>>

MODEM DEGRADATION (DGRMOD) =     0.00dB
PEAK-TO-AVERAGE LOSS (PEAKAV) =     1.25dB
```

SHORT TERM OUTAGE PROBABILITIES VS Eb/No

<< MDTS>>

==> BEGIN OUTPUT FOR: SNR = 28.0 DSNR = 6.0

FRACTION OF RECEIVED POWER DUE TO SCATTER XSCAT = 9.9373E-01
FRACTION OF RECEIVED POWER DUE TO DIFFRACTION XDIFR = 6.2700E-03

NORMALIZED SAMPLING TIME FOR AFE CENTER TAP (TO) = -3.7949E-03
DIFFRACTION PATH DELAY RELATIVE TO STRAIGHT LINE (DEL) = 1.3756E-07
AVERAGE TROPOSCATTER SIGNAL DELAY FOR BEAM 1 (TEMPA(1)) = 3.2970E-07
DELAY OF SCATTER COMPONENT (TSCAT) = 6.0525E-01
NORMALIZED DELAY BETWEEN UPPER AND LOWER BEAMS (TDIFF) = 4.4194E-01

<< MATCO>>

COVARIANCE MATRIX FOR AFE TAPS (C)

3.6014E-01	4.7563E-01	2.4062E-01	1.9419E-02	3.6465E-02	2.0193E-02
4.7563E-01	7.6219E-01	4.5428E-01	1.4310E-02	2.2685E-02	1.1922E-03
2.4062E-01	4.5428E-01	3.0583E-01	3.5552E-03	5.1156E-04	-1.3420E-02
1.9419E-02	1.4310E-02	3.5552E-03	4.2652E-02	7.3220E-02	4.4826E-02
3.6465E-02	2.2685E-02	5.1156E-04	7.3220E-02	1.4621E-01	1.0565E-01
2.0193E-02	1.1922E-03	-1.3420E-02	4.4826E-02	1.0565E-01	8.9538E-02

NOISE MATRIX FOR AFE TAPS (A)

9.0742E-01	5.0300E-01	4.5801E-02	0.0000E-01	0.0000E-01	0.0000E-01
5.0300E-01	9.0742E-01	5.0300E-01	0.0000E-01	0.0000E-01	0.0000E-01
4.5801E-02	5.0300E-01	9.0742E-01	0.0000E-01	0.0000E-01	0.0000E-01
0.0000E-01	0.0000E-01	0.0000E-01	9.0742E-01	5.0300E-01	4.5801E-02
0.0000E-01	0.0000E-01	0.0000E-01	5.0300E-01	9.0742E-01	5.0300E-01
0.0000E-01	0.0000E-01	0.0000E-01	4.5801E-02	5.0300E-01	9.0742E-01

ISI MATRIX FOR AFE TAPS (CSUM)

3.0901E-01	6.8884E-02	2.0849E-03	0.0000E-01	0.0000E-01	0.0000E-01
6.8884E-02	2.0228E-02	1.3360E-03	0.0000E-01	0.0000E-01	0.0000E-01
2.0849E-03	1.3360E-03	3.0365E-04	0.0000E-01	0.0000E-01	0.0000E-01
0.0000E-01	0.0000E-01	0.0000E-01	3.2465E-01	1.0182E-01	6.8218E-03
0.0000E-01	0.0000E-01	0.0000E-01	1.0182E-01	4.1241E-02	4.1181E-03
0.0000E-01	0.0000E-01	0.0000E-01	6.8218E-03	4.1181E-03	7.3517E-04

<< MDTS>>

DET C (DEX) = 4.2755E-10

ANGLE DIVERSITY EIGENVALUES

LOWER BEAM (U(1-K3))	5.544584E-01	3.449438E-02	7.476604E-04
UPPER BEAM (U(K2-K6))	1.087210E-01	9.792663E-03	6.548775E-05

FOR002.DAT for RUN [illegible] (continued)

```
SPACE AND/OR FREQUENCY DIVERSITY EIGENVALUES (U(K7-K9))
  5.54035E-01   3.68370E-02   8.10098E-04


      FSIG             Z
 4.514673E-03  4.556159E-01
 3.162826E-01  5.206692E-01
 6.736833E-01  1.059762E-01
 1.607356E-02 -6.704311E-02
 3.936297E-02 -7.330636E-02
 2.988041E-02  8.795509E-03
               4.556862E-01
               5.293159E-01
               1.043771E-01
```

<< BERCAL>>

MAIN BEAM DIV (ID)	DIV TYPE (XTYPE)	EXPLC DIV (ITOT)	Eb/No (SNR)	ERROR RATE THRESHOLD (P)	OUTAGE PROBABILITY (PFO)	FADE OUTAGE PER CALL-MINUTE (FCMIN)	BLOCK ERROR PROBABILITY (SUM2)	AVE BIT ERROR RATE (BERAV)	DSNR (DSNR)
4	2S/2F	4	28.0	1.00E-04	0.00E-01	0.00E-01	2.49E-17	2.49E-20	6.
2	2S	2	28.0	1.00E-04	3.70E-09	4.45E-08	4.07E-09	4.07E-12	6.
2	2S/2A	4	28.0	1.00E-04	0.00E-01	0.00E-01	1.24E-15	1.24E-18	6.

FOR002.DAT for RUN 2 (concluded)

<< PROUT>>

198 ITERATIONS

YEARLY FADE OUTAGE PROBABILITIES

AVERAGE FADE OUTAGE PROBABILITY

BER THRESHOLD (P)	2S/2F OUTAGE (BOUT)	2S OUTAGE (BOUT)	2S/2A OUTAGE (BOUT)
1.00E-04	7.681090E-02	8.728549E-02	6.267699E-02

FADE OUTAGE PER CALL MINUTE

BER THRESHOLD (P)	2S/2F OUTAGE (FOUT)	2S OUTAGE (FOUT)	2S/2A OUTAGE (FOUT)
1.00E-04	1.370707E-01	1.837523E-01	1.232714E-01

YEARLY BLOCK ERROR PROBABILITY

2S/2F ABE	2S ABE	2S/2A ABE
2.150948E-02	1.102030E-01	7.408438E-02

TROPO COMPLETED: 15-NOV-83 23:12:26

SUMPAG.OUT for RUN 2

```
TROPOSCATTER PATH CALCULATIONS       15-NOV-83  22:17:20

   Tx Site - Rx Site
   RUN 2:  TROPO/DIFFRACTION - MD-918           Page  1

                                  Tx Site        Rx Site

Site Elevations (AMSL):         4822.7 ft       7135.5 ft
Horizon T.O. Angles:              0.05 deg        0.56 deg
Antenna heights (AGL):            55.0 ft         55.0 ft
Antenna diameters:                88.6 ft         88.6 ft

Climate Type:    MIL-HDBK-417 CT

Freq.:     0.9 GHz ; Pathlength:  178.3 smi
Scat. ang.:   2.54 deg
Path asymmetry   s =  0.88deg /  1.67deg  =  0.5247

Transmit power:  100.0 W  ;  BW:     7.0 MHz

Line losses:  3.00 dB.   Atm. Abs. loss:  1.30dB

Beam   2-sigma del.spr.  Pathloss   RSL   (Reference values)

  1      131.7nsec        229.0 dB   -89.9 dBm
  2      204.1nsec        234.6 dB   -95.5 dBm

Correl.12:  0.0422   Receiver elevation angle diversity correlation
                     (El. Squint =    1.13 deg )
       13:  0.0019   Divergent paths space diversity correlation
                     ( Rx Horz.Ant.Spac.= 200.0 ft   )
Min freq. separation required for freq div. [MHz] =      9.950

Correlation or coherence bandwith [MHz] =      2.950

   TROPOSCATTER PATH LOSS LONG TERM DISTRIBUTION

                    50%        99%       99.99%
Path Loss(dB)     231.33     255.06     271.16
RSL(dBm)          -92.27    -116.00    -132.09

Standard deviation of troposcatter path loss distribution:   10.509dB

Effective path distance:     181.18km

        DIFFRACTION PATH LOSS LONG TERM DISTRIBUTION

                    50%        99%       99.99%
Path Loss(dB)     231.27     238.29     242.37
RSL(dBm)          -93.62    -100.65    -104.73

Standard deviation of diffraction path loss distribution:    2.982dB

Delay of tropo path relative to diffraction path:     192.14 nsec
```

TROPOSCATTER PATH CALCULATIONS

Tx Site - Rx Site
RUN 2: TROPO/DIFFRACTION - MD-918 Page 2

Modem Type: MD-918

Average Yearly Fade Outage Probability

DIVERSITY CONFIGURATION	2S/2F	2S	2S/2A
@ 1.00E-04 BER	7.68E-02	8.73E-02	6.27E-02

Yearly Fade Outage Per Call Minute Probability (YFOP)

DIVERSITY CONFIGURATION	2S/2F	2S	2S/2A
YFOP @ 1.00E-04 BER	1.37E-01	1.84E-01	1.23E-01

SUMPAG.OUT for RUN 2 (concluded)

```
     TROPOSCATTER PATH CALCULATIONS

        Tx Site - Rx Site
        RUN 2: TROPO/DIFFRACTION - MD-918           Page  3

Auxiliary data

LUNITS= 8 (smi -ft  -deg -GHz )

Desired receive beam correlations:
             11: prof
             12: prof
             13: prof
             22: prof

Theoretical reference path loss :     229.19 dB

Horizon dist.&elev.(AMSL):  88.0 smi 9127.5 ft        33.3 smi 9453.5 ft

Eff. earth radius factor= 1.33 Spectrum slope= 5.00

Integration resolution params. ERR=  0.001000 NACCU=   40

Height of top of common volume HHIGH =      20648.5 ft
Height of bottom of common volume HCOM =    12228.9 ft
No. of cells in integration = 16704
```

Example 3

This example illustrates the format of the FOR002.DAT and SUMPAG.OUT output files when the performance of the MD-918 modem is requested (MODPAT = 1) in the presence of adjacent channel interference (JPOW > -174) in the main beam. Both output files and the input files are listed next.

TROPO.DAT for RUN 3

```
--------------------------- Input File Version 1.0 ---------------------------
START -- * -- * -- * -- * -- * -- * -- * -- * -- * -- * -- * -- * -- * --
* LINK NAME from transmit site to receive site (40 character maximum)
RUN 3: TROPO - MD-918 - INTERFERENCE
* MODPAT:        0 = Propagation only,
*                1 = Propagation + MD-918 -- Default
*                2 = Propagation + AN/TRC-170
*                3 = Propagation + user-defined modem.
1
* ICLIME:  Climate class; 0 = NBS (default), 1 = MIL-HDBK-417, 2 = New
1
* CLIMAT:  Climate code (See user's manual sec. 3.2; 4 character maximum)
CT
* GPF:  Frequency Correction Factor (default = 1.0)
1.0
* YMIN,DEMIN:    YO(90), DE at minima in kilometers
*                (used only when ICLIME=2)
0  0
* YZERO,Y900:    YO(90) at DE = 0, YO(90) at DE .ge. 900 kilometers
*                (used only when ICLIME=2)
0  0
* DISTU:  Distance units (SMI/KM/NMI); 4 character maximum
SMI
* HDU:  Height, elevation, diameter units (FT/M); 4 character maximum
FT
* ANGU:  Angle units (DEG/MRAD); 4 character maximum
DEG
* FREQU:  Frequency units (GHZ/MHZ); 4 character maximum
GHZ
* POWERU:  Transmit power units (W/dBm); 4 character maximum
DBM
* TXPOW:  Transmit power (defaults = 70 dBm, 10000 W)
50
* F:  Frequency (See user's manual sec 3.2 for limitations) (GHZ/MHZ)
0.875
* SP, NFIG:  Service Probability, Noise Figure (defaults = 0.95, 4dB)
.95  4.0
* TLL,RLL:  Transmitter, receiver line losses in dB (defaults = 0, 0)
1.5  1.5
* D:  Great circle distance at sea level between transmitter and receiver
*     (SMI/KM/NMI)
178.3
* HTO, HRO:  Transmitter, receiver site elevations above sea level (FT/M)
4822.82  7135.81
* HT,HR:  Transmitter, receiver antenna heights above ground (FT/M)
55  55
* PTYPE:  0 or 10 = Troposcatter; 1 or 11 = Mixed Troposcatter-Diffraction
*         PTYPE = 10 or 11 yields no correlation matrix in SUMPAG.OUT
10
TROPOSCATTER-ONLY SECTION -- * -- * -- Data for PTYPE = 1 or 10 * -- * -- * --
* ITOFF:  0 = input THET, THER (default), 2 = compute THET, THER
2
* THET, THER:  Transmitter, receiver horizon elevation angles (DEG/MRAD)
.06  .60
* DLT, DLR:  Transmitter, receiver distances to horizon (KM/SMI/NMI)
88.0  33.3
* HLT, HLR:  Transmitter, receiver horizon elevations above sea level (FT/M)
```

TROPO.DAT for RUN 3 (continued)

```
9128  9454
* NTERR:  Set flag:       0 = HTE, HRE are input,
*                         1 = use AVETX, AVERX
*                         2 = use terrain elevations (HI) to calculate HTE, HRE
2
* HTE, HRE:  Effective transmitter, receiver antenna heights
*            above average terrain elevations (FT/M)
0  0
* AVETX, AVERX:  Transmitter, receiver average foreground terrain elevations
*                above sea level (FT/M)
797.27  1619.79
* NP1, NP2:  Transmitter, receiver number of terrain elevations.
*            (Equivalent to NPM(1), NPM(2) in source code.) (defaults = 1,0)
9  9
* HI(1:NP1+NP2):  Terrain elevations beginning with transmit site elevation
*                 and ending with receive site elevation (FT/M)
4822.82  3535  3500  3485  3200  4160  4500  5000  9128
9454  5800  5700  5600  5650  5500  5400  5500  7135.81
DIFFRACTION SECTION -- * -- * -- * -- Data for PTYPE = 1 or 11 * -- * -- * --
* NOBS:  Number of diffraction obstacles;  maximum = 3 (default = 1)
2
* HL(1:NOBS):  Obstacle elevations above sea level beginning with transmit
*              horizon HLT and ending with receive horizon HLR (FT/M)
9128  9454
* DL(1:NOBS):  Great circle obstacle distances from transmitter (SMI/NMI/KM)
88.0  145.0
* DS(1:NOBS):  Effective horizontal obstacle extents (SMI/NMI/KM)
 .04   .04
* NTERR:  Set flag:       0 = HTE, HRE ,HLEF are given next
*                         1 = use AVETX, AVERX, HLAV
*                         2 = use terrain elevations (HI) to calculate HTE, HRE
2
* HTE, HRE:  Effective transmitter, receiver antenna heights above
*            average terrain elevations.  Used only for NTERR = 0.  (FT/M)
0  0
* HLEF(1:NOBS):  Effective diffraction obstacle heights above average terrain
*                elevation.  Used only for NTERR = 0.  (FT/M)
0  0
* AVETX, AVERX:  Transmitter, receiver average terrain elevations above
*                sea level.  Used only for NTERR = 1.  (FT/M)
3400  7135
* HLAV(1:NOBS):  Average terrain elevation above sea level at each
*                diffraction point.  Used only for NTERR = 1.  (FT/M)
7800  8500
* NPM(1:NOBS+1):  Number of terrain elevations between each pair of diffraction
*                 obstacles. (Tx and Rx are end points.) (default = 1,0,0,0)
9  9  9
* HI(1:NPM(1) + ... + NPM(NOBS+1)):  Terrain elevation data beginning with
*      transmit site elevation and ending with receive site elevation (FT/M)
4822.82  3535  3500  3485  3200  4160  4500  5000  9128
9128  7250  7100  7250  7500  8000  8150  8000  9454
9454  5800  5700  5600  5650  5500  5400  5500  7135.81
DIVERSITY DATA INPUT SECTION -- * -- * -- * -- * -- * -- * -- * -- * -- * --
* DIVTYP: Diversity Type (default = 0)
*       0 = 2S     2S/2F         2S/2A    2S/2A/2F
*       1 = 2A     2F            2F/2A
*       2 = 2S/2P  2S/2P/2A
*     S = Space  F = Frequency  A = Angle  P = Polarization
```

TROPO.DAT for RUN 3 (continued)

```
0
* TDIAM:  Transmitter antenna aperture diameter (AT(1)) (FT/M)
88.58
* RDIAM:  Receiver antenna aperture diameter (AR(1)) (FT/M)
88.58
* TELH:  Transmitter antenna beam elevation above horizon (PSITEO(1)).  Input
*        an angle 4000 or greater to have TELH calculated.  (DEG/MRAD)
4000
* RELH:  Receiver antenna beam elevation above horizon (PSIREO(1)).  Input
*        an angle 4000 or greater to have RELH calculated.  (DEG/MRAD)
.27
* PHDIV:  Angle between upper and lower beams (Default = Beamwidth) (DEG/MRAD)
0.0
* TFLAG, TSEP:  TFLAG = Transmitter antenna spacing indicator
*               (TFLAG must be 0 for this version of TROPO.)
*               TSEP = Transmitter antenna separation (FT/M)
0  200
* RFLAG, RSEP:  RFLAG = Receiver antenna spacing indicator
*               (RFLAG must be 0 for this version of TROPO.)
*               RSEP = Receiver antenna separation (FT/M)
0  200
PROPAGATION DATA INPUT SECTION -- * -- * -- * -- * -- * -- * -- * -- * -- * --
* SEAN:  Refractivity at sea level (default = 0)
0
* ERFAC:  Effective Earth Radius Factor, K.  Recalculated if SEAN > 0.
*         (default = 1.33)
1.33
* SCPARM:  Wavenumber Spectrum Slope Parameter M for atmospheric turbulence.
*          Reset to 5 if Frequency < 1GHz.  (default = 3.66)
3.66
* NACCU, ERR:  Integration accuracy (truncation point) and resolution.
*              (defaults = 40, 0.001)
40  .001
* TAPOUT: Enter T to have simulator tap values output in FOR002.DAT (default),
*         enter F to suppress the calculations and output.
F
* SPE, MLAST: Simulator tap spacing in nanoseconds and
*             number of taps (defaults = 67 nsec, 16)
67  16
* KPROF:  Number of CN2 profile samples.  Maximum = NPROF  (See TROPAR.INC)
0
* HLOW,DELH:  Lowest height above sea level at which CN2 is specified (FT/M),
*             Spacing of CN2 samples (FT/M)
0  0
* CN2(KPROF):  The atmospheric structure constant height profile samples (FT/M)
0
MODEM INPUT SECTION -- * -- * -- * -- Data for MODPAT > 0 * -- * -- * -- * -- *
* IBW:  Bandwidth constraint indicator (default = 0)
*       0 = No filter, 1 = 99%, 2 = FCC-19311, 3 = user specified
1
* IFILTX,IFILRX:  Transmit, receive filter impulse response (For IBW = 3 only):
*                 0 = MD-918 filter for receiver or transmitter
*                 1 = AN/TRC-170 filter for transmitter (not used for receiver)
*                 2 = AN/TRC-170 filter for receiver (not used for transmitter)
0  0
* FCTX,FCRX:  Transmitter, receiver 3dB cut-off frequencies (For IBW = 3 only)
*             (MHZ only)
0  0
```

TROPO.DAT for RUN 3 (continued)

```
* NPOLTX,NPOLRX:  Number of transmitter, receiver poles of Butterworth filter
*                 (For IBW = 3 only)
0  0
* BW:  Bandwidth, (default = 7.0 MHz)  (MHZ only)
7.0
* DRATE:  Data rate (bits/second)  (default = 6.6E6 bits/second)
6.6E6
* NERT:  Bit error rate threshold indicator:
*        0 = all, 1 = 1.0E-3, 2 = 1.0E-4 (default), 3 = 1.0E-5
0
MD-918 MODEM INPUT SECTION -- * -- * -- * -- Data for MODPAT = 1 * -- * -- * --
* TAPW.  Normalized tap width.  Range = 0.25 through 1.0.  (default = .5)
.5
* LISI:  Number of future ISI contributors considered  (default = 2)
2
AN/TRC-170 MODEM INPUT SECTION -- * -- * -- Data for MODPAT = 2 * -- * -- * --
* TRCTYP:  0 = single frequency, DAR modem;
*          1 = two frequencies, AN/TRC-170 modem (default)
1.0
INTERFERENCE PARAMETER INPUT SECTION -- * -- * -- * -- * -- * -- * -- * --
* JPOW:  Interference Power Density (default = -1000dBm/Hz for no interference)
-124.
* JBW.  99% Interference Bandwidth (default = Bandwidth BW) (MHZ only)
7.0
* FJSEP:  Frequency separation between the interference signal and desired
*         signal (default = larger of BW and JBW) (MHZ only):
*               0.  = co-channel interference
*               > BW and JBW = adjacent channel interference
7.0
* MANG:  Number of interferer azimuth, elevation pairs (default = 1)
1
* (XANG(I), ELANG(I),I=1,MANG):  Interferer azimuth, elevation angle (above
*       horizon) pairs.  (default = 0,0)  (DEG/MRAD)
0 32 0.0
* MODSIG:  Interfering signal modulation format; 0 = FDM/FM, 1 = QPSK (default)
1
USER-SUPPLIED DIVERSITY INPUT SECTION -- * -- * -- * -- * -- * -- * -- * --
* NT, NR:  Number of transmit and receive ports;  Maximums = NTMX, NRMX
1  2
* AT(NT):  Transmitter antenna aperture diameter (FT/M)
28
* AR(NR):  Receiver antenna aperture diameter (FT/M)
2*30
* PSITEO(NT):  Transmitter beam elevation above horizon (DEG/MRAD)
4000
* PSIREO(NR):  Receiver beam elevation above horizon (DEG/MRAD)
2*.33966
* PSITAO(NT):  Transmitter beam azimuth (DEG/MRAD)
0
* PSIRAO(NR):  Receiver beam azimuth (DEG/MRAD)
0.  0.
* IPOLT(NT):  Transmitter polarizations (DEG/MRAD)
0
* IPOLR(NR):  Receiver polarizations (DEG/MRAD)
0  0
* ((IBR(I,J),J=I,NR),I=1,NR):  Beams and cross-beams at receiver.
*      Enter:  0 = correlation between receivers I and J is not desired
*              1 = only power (correlation) calculations are desired
```

TROPO.DAT for RUN 3 (concluded)

```
*               2 = power (correlation) per unit delay calculations are desired
2  2  2
* UTH(NT):  Transmitter horizontal offsets (FT/M)
0
* UTV(NT):  Transmitter vertical offsets (FT/M)
0
* UTL(NT):  Transmitter longitudinal offsets (FT/M)
0
* URH(NR):  Receiver horizontal offsets (FT/M)
0  0
* URV(NR):  Receiver vertical offsets (FT/M)
0  0
* URL(NR):  Receiver longitudinal offsets (FT/M)
0  0
END
```

FOR002.DAT for RUN 3 (continued)

LICIT DIVERSITY EIGENVALUES (U(1-K6))
. 30128E-01 4. 72294E-02 8. 63759E-03
. 67694E-04 3. 49872E-04 2. 44227E-05

<< BERCAL>>

'ERFERER DENSITY (JPOW) = -124. 00dBm/Hz JSR = 24. 00dB

TYP	Eb/No PER DIV	ERROR RATE THRESHOLD	OUTAGE PROBABILITY	FADE OUTAGE PER CALL MINUTE	BLOCK ERROR PROBABILITY	AVE BIT ERROR RATE
TYPE)	(SNR)	(P)	(PFO)	(FCMIN)	(SUM2)	(BERAV)
5/2F	26. 0	1. 00E-03	6. 85E-08	8. 22E-07	4. 02E-07	[illegible]
5/2F	26. 0	1. 00E-04	4. 80E-07	5. 76E-06	4. 02E-07	[illegible]
5/2F	26. 0	1. 00E-05	1. 94E-06	2. 32E-05	4. 02E-07	[illegible]

<< MDTS>>

PLICIT DIVERSITY EIGENVALUES (U(1-K6))
6. 71118E-01 5. 19377E-02 8. 89088E-03
1. 47650E-03 3. 55541E-04 2. 46342E-05

<< BERCAL>>

ITERFERER DENSITY (JPOW) = -124. 00dBm/Hz JSR = 26. 00dB

V TYP	Eb/No PER DIV	ERROR RATE THRESHOLD	OUTAGE PROBABILITY	FADE OUTAGE PER CALL MINUTE	BLOCK ERROR PROBABILITY	AVE BIT ERROR RATE
TYPE)	(SNR)	(P)	(PFO)	(FCMIN)	(SUM2)	(BERAV)
'S/2F	24. 0	1. 00E-03	6. 57E-07	7. 89E-06	3. 73E-06	3. 73E-09
'S/2F	24. 0	1. 00E-04	4. 09E-06	4. 90E-05	3. 73E-06	3. 73E-09
'S/2F	24. 0	1. 00E-05	1. 50E-05	1. 79E-04	3. 73E-06	3. 73E-09

<< MDTS>>

IPLICIT DIVERSITY EIGENVALUES (U(1-K6))
7. 05016E-01 5. 60876E-02 9. 06515E-03
2. 20865E-03 3. 59250E-04 2. 47326E-05

<< BERCAL>>

ITERFERER DENSITY (JPOW) = -124. 00dBm/Hz JSR = 28. 00dB

V TYP	Eb/No PER DIV	ERROR RATE THRESHOLD	OUTAGE PROBABILITY	FADE OUTAGE PER CALL MINUTE	BLOCK ERROR PROBABILITY	AVE BIT ERROR RATE
TYPE)	(SNR)	(P)	(PFO)	(FCMIN)	(SUM2)	(BERAV)
'S/2F	22. 0	1. 00E-03	5. 90E-06	7. 08E-05	3. 30E-05	3. 30E-08
'S/2F	22. 0	1. 00E-04	3. 20E-05	3. 84E-04	3. 30E-05	3. 30E-08
'S/2F	22. 0	1. 00E-05	1. 05E-04	1. 26E-03	3. 30E-05	3. 30E-08

FOR002.DAT for RUN 3 (continued)

SHORT TERM OUTAGE PROBABILITIES VS Eb/No

<< MATCO>>

VARIANCE MATRIX FOR AFE TAPS (C)

2.7765E-01	4.0560E-01	2.3031E-01	0.0000E-01	0.0000E-01	0.0000E-01
4.0560E-01	7.4267E-01	5.1013E-01	0.0000E-01	0.0000E-01	0.0000E-01
2.3031E-01	5.1013E-01	4.0194E-01	0.0000E-01	0.0000E-01	0.0000E-01
0.0000E-01	0.0000E-01	0.0000E-01	2.7765E-01	4.0560E-01	2.3031E-01
0.0000E-01	0.0000E-01	0.0000E-01	4.0560E-01	7.4267E-01	5.1013E-01
0.0000E-01	0.0000E-01	0.0000E-01	2.3031E-01	5.1013E-01	4.0194E-01

)ISE MATRIX FOR AFE TAPS (A)

9.0472E-01	5.0433E-01	4.6403E-02	0.0000E-01	0.0000E-01	0.0000E-01
5.0433E-01	9.0472E-01	5.0433E-01	0.0000E-01	0.0000E-01	0.0000E-01
4.6403E-02	5.0433E-01	9.0472E-01	0.0000E-01	0.0000E-01	0.0000E-01
0.0000E-01	0.0000E-01	0.0000E-01	9.0472E-01	5.0433E-01	4.6403E-02
0.0000E-01	0.0000E-01	0.0000E-01	5.0433E-01	9.0472E-01	5.0433E-01
0.0000E-01	0.0000E-01	0.0000E-01	4.6403E-02	5.0433E-01	9.0472E-01

SI MATRIX FOR AFE TAPS (CSUM)

4.0203E-01	1.0987E-01	3.6261E-03	0.0000E-01	0.0000E-01	0.0000E-01
1.0987E-01	3.5142E-02	1.4525E-03	0.0000E-01	0.0000E-01	0.0000E-01
3.6261E-03	1.4525E-03	9.0387E-05	0.0000E-01	0.0000E-01	0.0000E-01
0.0000E-01	0.0000E-01	0.0000E-01	4.0203E-01	1.0987E-01	3.6261E-03
0.0000E-01	0.0000E-01	0.0000E-01	1.0987E-01	3.5142E-02	1.4525E-03
0.0000E-01	0.0000E-01	0.0000E-01	3.6261E-03	1.4525E-03	9.0387E-05

ET C (DEX) = 1.7410E-07

<< MDTS>>

MPLICIT DIVERSITY EIGENVALUES (U(1-K6))

5.84457E-01 4.16692E-02 8.28527E-03
6.25762E-04 3.41363E-04 2.41225E-05

<< BERCAL>>

NTERFERER DENSITY (JPOW) = -124.00dBm/Hz JSR = 22.00dB

IV TYP (XTYPE)	Eb/No PER DIV (SNR)	ERROR RATE THRESHOLD (P)	OUTAGE PROBABILITY (PFO)	FADE OUTAGE PER CALL MINUTE (FCMIN)	BLOCK ERROR PROBABILITY (SUM2)	AVE BIT ERROR RATE (BERAV)
2S/2F	28.0	1.00E-03	7.00E-09	8.40E-08	4.27E-08	4.27E-11
2S/2F	28.0	1.00E-04	5.46E-08	6.55E-07	4.27E-08	4.27E-11
2S/2F	28.0	1.00E-05	2.39E-07	2.87E-06	4.27E-08	4.27E-11

<< MDTS>>

FOR002.DAT for RUN 3 (continued)

MD-918 MODEM OUTPUT PARAMETERS: SECTION 2

<< MDTS>>

```
   NORMALIZED INTERFERER BANDWIDTH (JBWX) =          2.121212E+00
   INTERFERER ANGLE (JANG) =                         0.32 deg
   DELAY/T (TZ) =                                     3.745E-03
   ANGLE LOSS (DBLOSS) =                             1.53 dB
   ASEP =                                             60.96 m

NUMBER OF CHIPS PER BIT (KGAIN):                     1

CHIP SEQUENCE (ASEQ)
   1              1
```

<< BOTAC>>

NO. OF AFE TAPS (K1) AND TAP WIDTH IN T UNITS (TAPW) = 3 0.50

INTERFERER COVARIANCE MATRIX (TAC)

1.320487E-03	4.485132E-05	-6.604925E-04	1.320221E-03	4.233420E-05	-6.559038E-04
4.485132E-05	1.320487E-03	4.485132E-05	4.735175E-05	1.320221E-03	4.233420E-05
-6.604925E-04	4.485132E-05	1.320487E-03	-6.647817E-04	4.735175E-05	1.320221E-03
1.320221E-03	4.735175E-05	-6.647817E-04	1.320487E-03	4.485132E-05	-6.604925E-04
4.233420E-05	1.320221E-03	4.735175E-05	4.485132E-05	1.320487E-03	4.485132E-05
-6.559038E-04	4.233420E-05	1.320221E-03	-6.604925E-04	4.485132E-05	1.320487E-03

<< MDTS>>

MODEM DEGRADATION (DGRMOD) =   0.00dB
PEAK-TO-AVERAGE LOSS (PEAKAV) =   1.26dB

FOR002.DAT for RUN 3 (continued)

FILTER DATA

<< BUTFIL>>

	TRANSMITTER		RECEIVER	
Filter type	0	(IFILTX)	0	(IFILRX)
Poles	2	(NPOLTX)	4	(NPOLRX)
Cut-off freq (MHz)	3.21	(FCUT1)	3.50	(FCUT2)

TRANSMISSION BANDWIDTH (MHz) (FCUT) = 7.0000

FILTER TYPE REFERS TO THE RECTANGULAR SECTION
= 0: FULL SYMBOL INTERVAL DURATION
= 1: HALF SYMBOL INTERVAL DURATION
= 2: NO RECTANGULAR SECTION

PEAK-TO-AVERAGE POWER RATIO (dB) (PEAKAV) = 1.2557

FOR002.DAT for RUN 3 (continued)

YEARLY DISTRIBUTION OF SHORT-TERM MEAN Eb/No

SERVICE PROBABILITY (SP) = 0.950

MEDIAN OF SHORT-TERM MEAN Eb/No (ASNR) 1.1147E+01
STANDARD DEVIATION (STSNR) 1.0509E+01
MEDIAN PATHLOSS (PMED) 231.32

PERCENTILE (NOT EXCEEDED) (TEMP1)	PATH LOSS (dB) (TLOSS)	RSL (dBm) (RSL)	MEAN Eb/No (SNR)
0.01	208.914	-69.853	33.551
0.10	212.180	-73.119	30.286
1.00	216.267	-77.206	26.198
10.00	222.416	-83.355	20.050
50.00	231.319	-92.258	11.147
90.00	243.364	-104.302	-0.898
99.00	255.051	-115.990	-12.585
99.90	263.792	-124.731	-21.326
99.99	271.148	-132.087	-28.682

FOR002.DAT for RUN 3 (continued)

TROPOSCATTER PROPAGATION OUTPUT PARAMETERS: SECTION 1

```
                                                                  <<   POWER>>

ATMOSPHERIC ABSORPTION LOSS (AA):                        1.304 dB
TRANSMIT BEAMWIDTH (BWT):                                0.9031 deg
RECEIVE BEAMWIDTH  (BWR):                                0.9031 deg

NUMBER OF INTEGRATION CELLS (ITER):                   16704

LONG TERM REFERENCE TROPOSCATTER PATH LOSS,
NO CLIMATE CORRECTION

REFERENCE PATH LOSS ON LOWER BEAM (TEMP1):             228.97 dB
REFERENCE PATH LOSS ON UPPER BEAM (TEMP2):             234.58 dB
CORRELATION COEFFICIENT BETWEEN LOWER AND
UPPER BEAM (RH1):                                        0.0421

APERTURE-TO-MEDIUM COUPLING LOSS (CPL): BEAM 1 1        11.39 dB
APERTURE-TO-MEDIUM COUPLING LOSS (CPL): BEAM 2 2        13.78 dB

CORRELATION COEFF FOR LONG TERM VARIABILITY (CORRLT): 0.735910E+00

RELATIVE AVERAGE DELAY OF LOWER BEAM (DEL1)            329.5 nsec
RELATIVE AVERAGE DELAY OF UPPER BEAM (DEL2)            469.8 nsec

2*SIGMA DELAY SPREAD LOWER BEAM (TAU22):               131.7 nsec
2*SIGMA DELAY SPREAD UPPER BEAM (TAU23):               204.0 nsec

ESTIMATED MAXIMUM DELAY SPREAD LOWER BEAM (TEMP1):  313.4 nsec

Tx RADIO HORIXON ELEVATION ANGLE (THET) =                7.85556E-04 rad
Rx RADIO HORIXON ELEVATION ANGLE (THER) =                9.70620E-03 rad

Tx SITE AVERAGE TERRAIN ELEVATIONS (AVETX) =           884.36 m
Rx SITE AVERAGE TERRAIN ELEVATIONS (AVERX) =          1635.03 m

EFFECTIVE TRANSMITTER HEIGHT (HTE) =                   602.36 m
EFFECTIVE RECEIVER HEIGHT (HRE) =                      556.63 m

EFFECTIVE DISTANCE (DE):                               181.18 km
MEDIAN CLIMATE CORRECTION FACTOR (VDE) =                 3.543 dB

  VARIABILITY DISTRIBUTION YO(QT,DE)

      100 QT%          YO(QT,DE)
        0.01             40.284
        0.10             33.025
        1.00             24.194
       10.00             12.097
       90.00             -9.804
       99.00            -17.843
       99.90            -23.628
       99.99            -28.431
```

FOR002.DAT for RUN 3 (continued)

MODEM PARAMETERS

```
RF BANDWIDTH CONSTRAINT (IBW):                               1
  0 = NO FILTER
  1 = 99% BANDWIDTH CONSTRAINT
  2 = FCC-19311 BANDWIDTH CONSTRAINT
  3 = USER-SPECIFIED TX AND RX FILTERS

BANDWIDTH (BW):                                              7.00 MHz
DATA RATE (DRATE):                                           6.6000 Mbits/sec

MODEM TYPE (MODPAT):                                         1
  1 = MD-918
  2 = AN/TRC-170 or DAR
  3 = User defined

NO. OF AFE TAPS (NTAP):                                      3
NO. OF FUTURE ISI CONTRIBUTORS CONSIDERED (LISI):            2
TAPWIDTH (TAPW):                   0.5000 (normalized)      0.15152 nsec


ERROR RATE THRESHOLD INDICATOR (NERT):                       0
  0 = ALL (1.0E-3 1.0E-4 1.0E-5)
  1 = 1.0E-3
  2 = 1.0E-4
  3 = 1.0E-5
```

INTERFERENCE PARAMETERS

```
  INTERFERENCE POWER DENSITY (JPOW):                      -124.00 dBm/Hz
    (FOR NO INTERFERENCE, DENSITY IS -1000dBm/Hz)

  99% INTERFERENCE BANDWIDTH (JBW):                          7.00 MHz

  FREQUENCY SEPARATION BETWEEN
  SYSTEM AND INTERFERENCE (FJSEP):                           7.00 MHz

  INTERFERENCE SIGNAL MODULATION (MODSIG):                   1
  (0 = FDM/FM, 1 = QPSK)

  INTERFERER FILTER INDICATOR (JFILT):                       0
    0 = NO FILTER
    1 = FILTER USED

NO. INTERFERER AZIMUTH,ELEVATION PAIRS (MANG):               1

INTERFERER AZIMUTH    INTERFERER ELEVATION
      (XANG)                 (ELANG)
     0.32 deg               0.00 deg
```

FOR002.DAT for RUN 3 (continued)

TRANSMITTER OFFSETS (RELATIVE LOCATION)

	HORIZONTAL (UTH)	VERTICAL (UTV)	LONGITUDINAL (UTL)
PORT 1	0.00 ft	55.00 ft	0.00 ft

RECEIVER OFFSETS (RELATIVE LOCATION)

	HORIZONTAL (URH)	VERTICAL (URV)	LONGITUDINAL (URL)
PORT 1	100.00 ft	55.00 ft	0.00 ft
PORT 2	100.00 ft	55.00 ft	0.00 ft
PORT 3	-100.00 ft	55.00 ft	0.00 ft
PORT 4	-100.00 ft	55.00 ft	0.00 ft

EFFECTIVE EARTH RADIUS FACTOR K (ERFAC): 1.3300
WAVENUMBER SPECTRUM SLOPE PARAMETER M (SCPARM): 5.00
PARAMETER FOR TERMINATION OF NUMERICAL INTEGRATION
(NACCU) 40
INTEGRATION RESOLUTION (ERR): 0.0010

FOR002.DAT for RUN 3 (continued)

```
  RECEIVE  (IPOLR): PORT 4                          0

ANGLE BETWEEN UPPER AND LOWER BEAM (PHDIV):         1.1289 deg

BEAM AND CROSS-CORRELATION BEAM INDICATORS
  0 = NO CALCULATION
  1 = POWER (CORRELATION) ONLY
  2 = DELAY (CROSS) POWER SPECTRUM
         IBR(1,1)  =  2
         IBR(1,2)  =  2
         IBR(1,3)  =  2
         IBR(1,4)  =  0
         IBR(2,2)  =  2
         IBR(2,3)  =  0
         IBR(2,4)  =  0
         IBR(3,3)  =  0
         IBR(3,4)  =  0
         IBR(4,4)  =  0
```

FOR002.DAT for RUN 3 (continued)

```
EVENLY SPACED TERRAIN ELEVATION ABOVE SEA LEVEL DATA IN ft
         NP1 =  9                  NP2 =  9
  TX - RADIO HORIZON         RADIO HORIZON - RX
        HI(1: 9)                  HI(10:18)
       4822.82                   9454.00
       3535.00                   5800.00
       3500.00                   5700.00
       3485.00                   5600.00
       3200.00                   5650.00
       4160.00                   5500.00
       4500.00                   5400.00
       5000.00                   5500.00
       9128.00                   7135.81

DIVERSITY TYPE (DIVTYP):                                0
  0 = DIVERSITY OPTIONS:
      2S/2F, 2S, 2S/2A, 2S/2A/2F
  1 = DIVERSITY OPTIONS:
      2A, 2F, 2F/2A
  2 = DIVERSITY OPTIONS:
      2S/2P, 2S/2P/2A
  S = SPACE F = FREQUENCY A = ANGLE P = POLARIZATION

NUMBER OF TRANSMIT PORTS (NT):                          1
NUMBER OF RECEIVE PORTS  (NR):                          4

TRANSMIT ANTENNA DIAMETER (AT): PORT 1                 88.58 ft

RECEIVE ANTENNA DIAMETER (AR):  PORT 1                 88.58 ft
RECEIVE ANTENNA DIAMETER (AR):  PORT 2                 88.58 ft
RECEIVE ANTENNA DIAMETER (AR):  PORT 3                 88.58 ft
RECEIVE ANTENNA DIAMETER (AR):  PORT 4                 88.58 ft

ANTENNA BORESIGHT ELEVATION ABOVE REFERENCE HORIZON
  TRANSMIT (PSITEO): PORT 1                             0.2258 deg  --> Angle calculated

  RECEIVE  (PSIREO): PORT 1                             0.2258 deg  --> Angle calculated
  RECEIVE  (PSIREO): PORT 2                             1.3547 deg  --> Angle calculated
  RECEIVE  (PSIREO): PORT 3                             0.2258 deg  --> Angle calculated
  RECEIVE  (PSIREO): PORT 4                             1.3547 deg  --> Angle calculated

ANTENNA BORESIGHT AZIMUTH, DEFINES
THE ANGLE TO THE GREAT-CIRCLE PLANE
 POSITIVE COUNTER-CLOCKWISE FOR TRANSMIT
 POSITIVE CLOCKWISE FOR RECEIVE
  TRANSMIT (PSITAO): PORT 1                             0.0000 deg

  RECEIVE  (PSIRAO): PORT 1                             0.0000 deg
  RECEIVE  (PSIRAO): PORT 2                             0.0000 deg
  RECEIVE  (PSIRAO): PORT 3                             0.0000 deg
  RECEIVE  (PSIRAO): PORT 4                             0.0000 deg

POLARIZATIONS
  TRANSMIT (IPOLT): PORT 1                              0

  RECEIVE  (IPOLR): PORT 1                              0
  RECEIVE  (IPOLR): PORT 2                              0
  RECEIVE  (IPOLR): PORT 3                              0
```

FOR002.DAT for RUN 3 (continued)

```
TRANSMIT POWER (PXMIT):                                  50.00 dBm
TRANSMIT POWER (WLT):                                   100.00 W

FREQUENCY (F):                                            0.87 GHz

SERVICE PROBABILITY (SP):                                 0.950
NOISE FIGURE (NFIG):                                      4.00 dB

TRANSMITTER LINE LOSS (TLL):                              1.50 dB
RECEIVER LINE LOSS (RLL):                                 1.50 dB

TERMINAL DISTANCE (D):                                  178.30 smi

SITE ELEVATION ABOVE SEA LEVEL:
  TRANSMITTER (HTO)                                    4822.82 ft
  RECEIVER    (HRO)                                    7135.81 ft

ANTENNA HEIGHT ABOVE GROUND:
  TRANSMITTER (HT)                                       55.00 ft
  RECEIVER    (HR)                                       55.00 ft

ANTENNA HEIGHTS ABOVE SEA LEVEL:
  TX HTS=HTO+HT                                        4877.82 ft
  RX HRS=HRO+HR                                        7190.81 ft

PATH CALCULATION INDICATOR (PTYPE):                       0
  0 = TROPOSCATTER ONLY
  1 = MIXED TROPOSCATTER-DIFFRACTION OR DIFFRACTION ONLY
      PTYPE = 10 OR 11 EQUIVALENT TO PTYPE = 0 OR 1
      WITH POWER VS DELAY PROFILE OUTPUT SUPPRESSED

TAKE-OFF ANGLES CALCULATION INDICATOR (ITOFF):            2
   0 = SPECIFIED IN INPUT
   1 = CALCULATED USING K (ERFAC) = 1.33
   2 = CALCULATED USING INPUT SPECIFIED K (ERFAC) VALUE
   3 = UNCHANGED FROM PREVIOUS VALUE

DISTANCE TO HORIZON,MEASURED AT SEA LEVEL
  TRANSMITTER (DLT):                                     88.00 smi
  RECEIVER (DLR):                                        33.30 smi

HEIGHT ABOVE SEA LEVEL OF
  TRANSMIT HORIZON OBSTACLE (HLT):                     9128.00 ft
  RECEIVE HORIZON OBSTACLE (HLR):                      9454.00 ft

HTE,HRE DATA INDICATOR (NTERR):                           2
  0 = USER-SUPPLIED
  1 = AVETX,AVERX DATA
  2 = TERRAIN ELEVATION DATA
```

FOR002.DAT for RUN 3 (continued)

```
26 = nmi ft  deg  MHz
```

FOR002.DAT for RUN 3

```
*** INPUT PARAMETERS *** 15-NOV-83  23:12:27

                                                       << OUTDAT>>

                         PATH PARAMETERS
                         ---------------

LINK NAME (LNAME): RUN 3: TROPO - MD-918 - INTERFERENCE

PATH/MODEM INDICATOR (MODPAT):      1
  0 = Path only
  1 = Path + MD-918 modem
  2 = Path + AN/TRC-170 or DAR modem
  3 = Path + user defined modem

CLIMATE CLASS (ICLIME):             1
  0 = NBS TN101 CLIMATE
  1 = MIL-HDBK-417 CLIMATE
  2 = NEW USER-SUPPLIED CLIMATE

CLIMATE (CLIMAT):     CT

 NBS CLIMATES:
   CT    = CONTINENTAL TEMPERATE
   MTL   = MARITIME TEMPERATE OVERLAND
   MTS   = MARITIME TEMPERATE OVERSEA
   MSL   = MARITIME SUBTROPICAL OVERLAND
   CT2   = CONTINENTAL TEMPERATE TIME BLOCK 2
   DS    = DESERT, SAHARA
   EQU   = EQUATORIAL
   CS    = CONTINENTAL SUBTROPIC
   CTD   = MIXED CLIMATES - CT AND DS
   MTLD  = MIXED CLIMATES - MTL AND DS

 MIL-HDBK-417 CLIMATES:
   CT    = CONTINENTAL TEMPERATE
   MTL   = MARITIME TEMPERATE OVERLAND
   MTS   = MARITIME TEMPERATE OVERSEA
   MS    = MARITIME SUBTROPICAL
   DS    = DESERT, SAHARA
   EQU   = EQUATORIAL
   CS    = CONTINENTAL SUBTROPICAL
   MED   = MEDITERRANEAN
   POL   = POLAR

I/O UNITS INDICATOR (LUNITS):  8 = smi  ft   deg  GHz
   0 = smi  ft   mrad GHz
   1 = km   m    mrad GHz
   2 = nmi  ft   mrad GHz
   8 = smi  ft   deg  GHz
   9 = km   m    deg  GHz
  10 = nmi  ft   deg  GHz
  16 = smi  ft   mrad MHz
  17 = km   m    mrad MHz
  18 = nmi  ft   mrad MHz
  24 = smi  ft   deg  MHz
  25 = km   m    deg  MHz
```

***** Ignoring PSITEO and PSIREO input. Calculating angles.

FOR002.DAT for RUN 3 (continued)

<< MDTS>>

IMPLICIT DIVERSITY EIGENVALUES (U(1-K6))
7.31584E-01 6.01305E-02 9.18160E-03
3.21109E-03 3.61661E-04 2.48212E-05

<< BERCAL>>

INTERFERER DENSITY (JPOW) = -124.00dBm/Hz JSR = 30.00dB

DIV TYP (XTYPE)	Eb/No PER DIV (SNR)	ERROR RATE THRESHOLD (P)	OUTAGE PROBABILITY (PFO)	FADE OUTAGE PER CALL MINUTE (FCMIN)	BLOCK ERROR PROBABILITY (SUM2)	AVE BIT ERROR RATE (BERAV)
2S/2F	20.0	1.00E-03	4.72E-05	5.66E-04	2.67E-04	2.67E-07
2S/2F	20.0	1.00E-04	2.18E-04	2.61E-03	2.67E-04	2.67E-07
2S/2F	20.0	1.00E-05	6.32E-04	7.55E-03	2.67E-04	2.67E-07

<< MDTS>>

IMPLICIT DIVERSITY EIGENVALUES (U(1-K6))
7.52040E-01 6.45533E-02 9.25781E-03
4.49184E-03 3.63194E-04 2.48851E-05

<< BERCAL>>

INTERFERER DENSITY (JPOW) = -124.00dBm/Hz JSR = 32.00dB

DIV TYP (XTYPE)	Eb/No PER DIV (SNR)	ERROR RATE THRESHOLD (P)	OUTAGE PROBABILITY (PFO)	FADE OUTAGE PER CALL MINUTE (FCMIN)	BLOCK ERROR PROBABILITY (SUM2)	AVE BIT ERROR RATE (BERAV)
2S/2F	18.0	1.00E-03	3.20E-04	3.83E-03	1.91E-03	1.91E-06
2S/2F	18.0	1.00E-04	1.25E-03	1.49E-02	1.91E-03	1.91E-06
2S/2F	18.0	1.00E-05	3.18E-03	3.75E-02	1.91E-03	1.91E-06

<< MDTS>>

IMPLICIT DIVERSITY EIGENVALUES (U(1-K6))
7.68105E-01 6.97519E-02 9.30711E-03
5.98663E-03 3.64163E-04 2.48380E-05

<< BERCAL>>

INTERFERER DENSITY (JPOW) = -124.00dBm/Hz JSR = 34.00dB

DIV TYP (XTYPE)	Eb/No PER DIV (SNR)	ERROR RATE THRESHOLD (P)	OUTAGE PROBABILITY (PFO)	FADE OUTAGE PER CALL MINUTE (FCMIN)	BLOCK ERROR PROBABILITY (SUM2)	AVE BIT ERROR RATE (BERAV)
2S/2F	16.0	1.00E-03	1.79E-03	2.13E-02	1.18E-02	1.18E-05
2S/2F	16.0	1.00E-04	5.89E-03	6.85E-02	1.18E-02	1.18E-05

2S/2F	16.0	1.00E-05	1.32E-02	1.48E-01	1.18E-02	1.18E-05

<< MDTS>>

IMPLICIT DIVERSITY EIGENVALUES (U(1-K6))
7.81295E-01 7.58783E-02 9.33870E-03
7.55279E-03 3.64774E-04 2.48860E-05

<< BERCAL>>

INTERFERER DENSITY (JPOW) = -124.00dBm/Hz JSR = 36.00dB

DIV TYP (XTYPE)	Eb/No PER DIV (SNR)	ERROR RATE THRESHOLD (P)	OUTAGE PROBABILITY (PFO)	FADE OUTAGE PER CALL MINUTE (FCMIN)	BLOCK ERROR PROBABILITY (SUM2)	AVE BIT ERROR RATE (BERAV)
2S/2F	14.0	1.00E-03	8.23E-03	9.44E-02	6.33E-02	6.33E-05
2S/2F	14.0	1.00E-04	2.28E-02	2.42E-01	6.33E-02	6.33E-05
2S/2F	14.0	1.00E-05	4.51E-02	4.25E-01	6.33E-02	6.33E-05

<< MDTS>>

IMPLICIT DIVERSITY EIGENVALUES (U(1-K6))
7.92554E-01 8.27041E-02 9.35997E-03
9.01553E-03 3.65181E-04 2.48760E-05

<< BERCAL>>

INTERFERER DENSITY (JPOW) = -124.00dBm/Hz JSR = 38.00dB

DIV TYP (XTYPE)	Eb/No PER DIV (SNR)	ERROR RATE THRESHOLD (P)	OUTAGE PROBABILITY (PFO)	FADE OUTAGE PER CALL MINUTE (FCMIN)	BLOCK ERROR PROBABILITY (SUM2)	AVE BIT ERROR RATE (BERAV)
2S/2F	12.0	1.00E-03	3.10E-02	3.14E-01	2.92E-01	2.92E-04
2S/2F	12.0	1.00E-04	7.25E-02	5.95E-01	2.92E-01	2.92E-04
2S/2F	12.0	1.00E-05	1.27E-01	8.03E-01	2.92E-01	2.92E-04

<< MDTS>>

IMPLICIT DIVERSITY EIGENVALUES (U(1-K6))
8.02243E-01 8.96474E-02 1.02469E-02
9.37084E-03 3.65439E-04 2.49356E-05

<< BERCAL>>

INTERFERER DENSITY (JPOW) = -124.00dBm/Hz JSR = 40.00dB

DIV TYP (XTYPE)	Eb/No PER DIV (SNR)	ERROR RATE THRESHOLD (P)	OUTAGE PROBABILITY (PFO)	FADE OUTAGE PER CALL MINUTE (FCMIN)	BLOCK ERROR PROBABILITY (SUM2)	AVE BIT ERROR RATE (BERAV)

2S/2F	10.0	1.00E-03	9.54E-02	7.00E-01	1.00E+00	1.17E-03
2S/2F	10.0	1.00E-04	1.89E-01	9.19E-01	1.00E+00	1.17E-03
2S/2F	10.0	1.00E-05	2.92E-01	9.84E-01	1.00E+00	1.17E-03

<< MDTS>>

IMPLICIT DIVERSITY EIGENVALUES (U(1-K6))
8.10334E-01 9.60208E-02 1.11920E-02
9.37922E-03 3.65591E-04 2.48655E-05

<< BERCAL>>

INTERFERER DENSITY (JPOW) = -124.00dBm/Hz JSR = 42.00dB

DIV TYP (XTYPE)	Eb/No PER DIV (SNR)	ERROR RATE THRESHOLD (P)	OUTAGE PROBABILITY (PFO)	FADE OUTAGE PER CALL MINUTE (FCMIN)	BLOCK ERROR PROBABILITY (SUM2)	AVE BIT ERROR RATE (BERAV)
2S/2F	8.0	1.00E-03	2.38E-01	9.62E-01	1.00E+00	4.02E-03
2S/2F	8.0	1.00E-04	3.99E-01	9.98E-01	1.00E+00	4.02E-03
2S/2F	8.0	1.00E-05	5.43E-01	1.00E+00	1.00E+00	4.02E-03

<< MDTS>>

IMPLICIT DIVERSITY EIGENVALUES (U(1-K6))
8.16761E-01 1.01331E-01 1.18725E-02
9.38437E-03 3.65716E-04 2.49356E-05

<< BERCAL>>

INTERFERER DENSITY (JPOW) = -124.00dBm/Hz JSR = 44.00dB

DIV TYP (XTYPE)	Eb/No PER DIV (SNR)	ERROR RATE THRESHOLD (P)	OUTAGE PROBABILITY (PFO)	FADE OUTAGE PER CALL MINUTE (FCMIN)	BLOCK ERROR PROBABILITY (SUM2)	AVE BIT ERROR RATE (BERAV)
2S/2F	6.0	1.00E-03	4.77E-01	1.00E+00	1.00E+00	1.19E-02
2S/2F	6.0	1.00E-04	6.71E-01	1.00E+00	1.00E+00	1.19E-02
2S/2F	6.0	1.00E-05	8.03E-01	1.00E+00	1.00E+00	1.19E-02

<< MDTS>>

IMPLICIT DIVERSITY EIGENVALUES (U(1-K6))
8.21585E-01 1.05410E-01 1.23402E-02
9.38756E-03 3.65751E-04 2.48822E-05

<< BERCAL>>

INTERFERER DENSITY (JPOW) = -124.00dBm/Hz JSR = 46.00dB

DIV TYP	Eb/No PER	ERROR RATE	OUTAGE PROBABILITY	FADE OUTAGE PER	BLOCK ERROR	AVE BIT ERROR

	DIV	THRESHOLD		CALL MINUTE	PROBABILITY	RATE
(XTYPE)	(SNR)	(P)	(PFO)	(FCMIN)	(SUM2)	(BERAV)
2S/2F	4.0	1.00E-03	7.50E-01	1.00E+00	1.00E+00	2.98E-02
2S/2F	4.0	1.00E-04	8.93E-01	1.00E+00	1.00E+00	2.98E-02
2S/2F	4.0	1.00E-05	9.57E-01	1.00E+00	1.00E+00	2.98E-02

<< MDTS>>

IMPLICIT DIVERSITY EIGENVALUES (U(1-K6))
8.25035E-01 1.08355E-01 1.26521E-02
9.38970E-03 3.65794E-04 2.49425E-05

<< BERCAL>>

INTERFERER DENSITY (JPOW) = -124.00dBm/Hz JSR = 48.00dB

DIV TYP	Eb/No PER DIV	ERROR RATE THRESHOLD	OUTAGE PROBABILITY	FADE OUTAGE PER CALL MINUTE	BLOCK ERROR PROBABILITY	AVE BIT ERROR RATE
(XTYPE)	(SNR)	(P)	(PFO)	(FCMIN)	(SUM2)	(BERAV)
2S/2F	2.0	1.00E-03	9.35E-01	1.00E+00	1.00E+00	6.37E-02
2S/2F	2.0	1.00E-04	9.85E-01	1.00E+00	1.00E+00	6.37E-02
2S/2F	2.0	1.00E-05	9.97E-01	1.00E+00	1.00E+00	6.37E-02

<< MDTS>>

IMPLICIT DIVERSITY EIGENVALUES (U(1-K6))
8.27401E-01 1.10387E-01 1.28559E-02
9.39093E-03 3.65811E-04 2.49370E-05

<< BERCAL>>

INTERFERER DENSITY (JPOW) = -124.00dBm/Hz JSR = 50.00dB

DIV TYP	Eb/No PER DIV	ERROR RATE THRESHOLD	OUTAGE PROBABILITY	FADE OUTAGE PER CALL MINUTE	BLOCK ERROR PROBABILITY	AVE BIT ERROR RATE
(XTYPE)	(SNR)	(P)	(PFO)	(FCMIN)	(SUM2)	(BERAV)
2S/2F	0.0	1.00E-03	9.94E-01	1.00E+00	1.00E+00	1.16E-01
2S/2F	0.0	1.00E-04	9.99E-01	1.00E+00	1.00E+00	1.16E-01
2S/2F	0.0	1.00E-05	1.00E+00	1.00E+00	1.00E+00	1.16E-01

<< MDTS>>

IMPLICIT DIVERSITY EIGENVALUES (U(1-K6))
8.28978E-01 1.11746E-01 1.29870E-02
9.39183E-03 3.65830E-04 2.49417E-05

<< BERCAL>>

INTERFERER DENSITY (JPOW) = -124.00dBm/Hz JSR = 52.00dB

FOR002.DAT for RUN 3 (continued)

DIV TYP (XTYPE)	Eb/No PER DIV (SNR)	ERROR RATE THRESHOLD (P)	OUTAGE PROBABILITY (PFO)	FADE OUTAGE PER CALL MINUTE (FCMIN)	BLOCK ERROR PROBABILITY (SUM2)	AVE BIT ERROR RATE (BERAV)
2S/2F	-2.0	1.00E-03	1.00E+00	1.00E+00	1.00E+00	1.83E-01
2S/2F	-2.0	1.00E-04	1.00E+00	1.00E+00	1.00E+00	1.83E-01
2S/2F	-2.0	1.00E-05	1.00E+00	1.00E+00	1.00E+00	1.83E-01

<< MDTS>>

IMPLICIT DIVERSITY EIGENVALUES (U(1-K6))
8.30016E-01 1.12637E-01 1.30714E-02
9.39225E-03 3.65840E-04 2.48833E-05

<< BERCAL>>

INTERFERER DENSITY (JPOW) = -124.00dBm/Hz JSR = 54.00dB

DIV TYP (XTYPE)	Eb/No PER DIV (SNR)	ERROR RATE THRESHOLD (P)	OUTAGE PROBABILITY (PFO)	FADE OUTAGE PER CALL MINUTE (FCMIN)	BLOCK ERROR PROBABILITY (SUM2)	AVE BIT ERROR RATE (BERAV)
2S/2F	-4.0	1.00E-03	1.00E+00	1.00E+00	1.00E+00	2.54E-01
2S/2F	-4.0	1.00E-04	1.00E+00	1.00E+00	1.00E+00	2.54E-01
2S/2F	-4.0	1.00E-05	1.00E+00	1.00E+00	1.00E+00	2.54E-01

<< MDTS>>

IMPLICIT DIVERSITY EIGENVALUES (U(1-K6))
8.30684E-01 1.13213E-01 1.31248E-02
9.39263E-03 3.65860E-04 2.49259E-05

<< BERCAL>>

INTERFERER DENSITY (JPOW) = -124.00dBm/Hz JSR = 56.00dB

DIV TYP (XTYPE)	Eb/No PER DIV (SNR)	ERROR RATE THRESHOLD (P)	OUTAGE PROBABILITY (PFO)	FADE OUTAGE PER CALL MINUTE (FCMIN)	BLOCK ERROR PROBABILITY (SUM2)	AVE BIT ERROR RATE (BERAV)
2S/2F	-6.0	1.00E-03	1.00E+00	1.00E+00	1.00E+00	3.20E-01
2S/2F	-6.0	1.00E-04	1.00E+00	1.00E+00	1.00E+00	3.20E-01
2S/2F	-6.0	1.00E-05	1.00E+00	1.00E+00	1.00E+00	3.20E-01

FOR002.DAT for RUN 3 (concluded)

<< PROUT>>

YEARLY FADE OUTAGE PROBABILITIES

AVERAGE FADE OUTAGE PROBABILITY

BER THRESHOLD (P)	2S/2F OUTAGE (BOUT)
1.00E-03	2.905928E-01
1.00E-04	3.406562E-01
1.00E-05	3.803588E-01

FADE OUTAGE PER CALL MINUTE

BER THRESHOLD (P)	2S/2F OUTAGE (FOUT)
1.00E-03	4.801880E-01
1.00E-04	5.378867E-01
1.00E-05	5.811469E-01

YEARLY BLOCK ERROR PROBABILITY 2S/2F ABE: 5.018345E-01

TROPO COMPLETED: 15-NOV-83 23:14:37

SUMPAG.OUT for RUN 3

```
TROPOSCATTER PATH CALCULATIONS      15-NOV-83  23:12:27

   Tx Site - Rx Site
   RUN 3: TROPO - MD-918 - INTERFERENCE        Page  1

                                Tx Site       Rx Site

Site Elevations (AMSL):       4822.7 ft     7135.5 ft
Horizon T.O. Angles:            0.05 deg      0.56 deg
Antenna heights (AGL):          55.0 ft       55.0 ft
Antenna diameters:              88.6 ft       88.6 ft

Climate Type:   MIL-HDBK-417 CT

Freq.:     0.9 GHz ; Pathlength:  178.3 smi
Scat. ang.:  2.54 deg
Path asymmetry  s =  0.87deg /  1.67deg  =  0.5247

Transmit power:  100.0 W  ;  BW:     7.0 MHz

Line losses:  3.00 dB.   Atm. Abs. loss:  1.30dB

Beam   2-sigma del.spr.  Pathloss   RSL   (Reference values)

  1      131.7nsec       229.0 dB   -89.9 dBm
  2      204.0nsec       234.6 dB   -95.5 dBm

Correl.12: 0.0421   Receiver elevation angle diversity correlation
                    (El. Squint =    1.13 deg )
       13: 0.0019   Divergent paths space diversity correlation
                    ( Rx Horz.Ant.Spac.= 200.0 ft  )
Min freq. separation required for freq div. [MHz] =     9.951

Correlation or coherence bandwith [MHz] =     2.951

   TROPOSCATTER PATH LOSS LONG TERM DISTRIBUTION

                  50%       99%      99.99%
Path Loss(dB)   231.32    255.05    271.15
RSL(dBm)        -92.26   -115.99   -132.09

Standard deviation of troposcatter path loss distribution:  10.509dB

Effective path distance:     181.18km

Interference power density:  -124.0 dBm/Hz
Interference signal modulation format;  Digital QPSK
```

TROPOSCATTER PATH CALCULATIONS

Tx Site - Rx Site
RUN 3: TROPO - MD-918 - INTERFERENCE Page 2

Modem Type: MD-918

Average Yearly Fade Outage Probability

DIVERSITY CONFIGURATION	2S/2F
@ 1.00E-04 BER	3.41E-01

Yearly Fade Outage Per Call Minute Probability (YFOP)

DIVERSITY CONFIGURATION	2S/2F
YFOP @ 1.00E-04 BER	5.38E-01

SUMPAG.OUT for RUN 3 (concluded)

```
     TROPOSCATTER PATH CALCULATIONS

        Tx Site - Rx Site
        RUN 3:  TROPO - MD-918 - INTERFERENCE          Page  3

Auxiliary data

LUNITS= 8 (smi -ft  -deg -GHz )

Desired receive beam correlations:
            11: prof
            12: prof
            13: prof
            22: prof

Theoretical reference path loss :     229.19 dB

Horizon dist.&elev.(AMSL):  88.0 smi 9127.5 ft        33.3 smi 9453.5 ft

Eff. earth radius factor= 1.33 Spectrum slope= 5.00

Integration resolution params. ERR=  0.001000 NACCU=   40

Height of top of common volume HHIGH =      20645.8 ft
Height of bottom of common volume HCOM =    12226.1 ft
No. of cells in integration = 16704
```

Example 4

This example illustrates the format of the FOR002.DAT and SUMPAG.OUT output files when the performance of the TRC-170/DAR modem is requested (MODPAT = 2). The input file is similar to that for Example 1 except for the following: MODPAT=2, TRCTYP=1, BW=3.5 MHz, DRATE=2.048 Mb bits/sec.

TROPO.DAT for RUN 4

```
------------------------- Input File Version 1.0 -------------------------
START -- * -- * -- * -- * -- * -- * -- * -- * -- * -- * -- * -- * -- * --
* LINK NAME from transmit site to receive site (40 character maximum)
RUN 4: TROPO - AN/TRC-170
* MODPAT:        0 = Propagation only,
*                1 = Propagation + MD-918 -- Default
*                2 = Propagation + AN/TRC-170
*                3 = Propagation + user-defined modem.
2
* ICLIME:  Climate class; 0 = NBS (default), 1 = MIL-HDBK-417, 2 = New
1
* CLIMAT:  Climate code (See user's manual sec. 3.2; 4 character maximum)
CT
* GPF:  Frequency Correction Factor (default = 1.0)
1.0
* YMIN,DEMIN:    YO(90), DE at minima in kilometers
*                (used only when ICLIME=2)
0  0
* YZERO,Y900:    YO(90) at DE = 0, YO(90) at DE .ge. 900 kilometers
*                (used only when ICLIME=2)
0  0
* DISTU:  Distance units (SMI/KM/NMI); 4 character maximum
SMI
* HDU:  Height, elevation, diameter units (FT/M); 4 character maximum
FT
* ANGU:  Angle units (DEG/MRAD); 4 character maximum
DEG
* FREQU:  Frequency units (GHZ/MHZ); 4 character maximum
GHZ
* POWERU:  Transmit power units (W/dBm); 4 character maximum
DBM
* TXPOW:  Transmit power (defaults = 70 dBm, 10000 W)
50
* F:  Frequency (See user's manual sec 3.2 for limitations) (GHZ/MHZ)
0.875
* SP, NFIG:  Service Probability, Noise Figure (defaults = 0.95, 4dB)
.95  4.0
* TLL,RLL:  Transmitter, receiver line losses in dB (defaults = 0, 0)
1.5  1.5
* D:  Great circle distance at sea level between transmitter and receiver
*     (SMI/KM/NMI)
178.3
* HTO, HRO:  Transmitter, receiver sit  elevations above sea level (FT/M)
4822.82  7135.81
* HT,HR:  Transmitter, receiver antenna heights above ground (FT/M)
55  55
* PTYPE:  0 or 10 = Troposcatter; 1 or 11 = Mixed Troposcatter-Diffraction
*         PTYPE = 10 or 11 yields no correlation matrix in SUMPAG.OUT
10
TROPOSCATTER-ONLY SECTION -- * -- * -- Data for PTYPE = 1 or 10 * -- * -- * --
* ITOFF:  0 = input THET, THER (default), 2 = compute THET, THER
2
* THET, THER:  Transmitter, receiver horizon elevation angles (DEG/MRAD)
.06  .60
* DLT, DLR:  Transmitter, receiver distances to horizon (KM/SMI/NMI)
88.0  33.3
* HLT, HLR:  Transmitter, receiver horizon elevations above sea level (FT/M)
```

```
9128  9454
* NTERR:  Set flag:      0 = HTE, HRE are input,
*                        1 = use AVETX, AVERX
*                        2 = use terrain elevations (HI) to calculate HTE, HRE
2
* HTE, HRE:  Effective transmitter, receiver antenna heights
*            above average terrain elevations (FT/M)
0  0
* AVETX, AVERX:  Transmitter, receiver average foreground terrain elevations
*                above sea level (FT/M)
797.27  1619.79
* NP1, NP2:  Transmitter, receiver number of terrain elevations.
*            (Equivalent to NPM(1), NPM(2) in source code.) (defaults = 1,0)
9  9
* HI(1:NP1+NP2):  Terrain elevations beginning with transmit site elevation
*                 and ending with receive site elevation (FT/M)
4822.82  3535  3500  3485  3200  4160  4500  5000  9128
9454  5800  5700  5600  5650  5500  5400  5500  7135.81
DIFFRACTION SECTION -- * -- * -- * -- Data for PTYPE = 1 or 11 * -- * -- * --
* NOBS:  Number of diffraction obstacles;  maximum = 3 (default = 1)
2
* HL(1:NOBS):  Obstacle elevations above sea level beginning with transmit
*              horizon HLT and ending with receive horizon HLR (FT/M)
9128  9454
* DL(1:NOBS):  Great circle obstacle distances from transmitter (SMI/NMI/KM)
88.0  145.0
* DS(1:NOBS):  Effective horizontal obstacle extents (SMI/NMI/KM)
.04  .04
* NTERR:  Set flag:      0 = HTE, HRE ,HLEF are given next
*                        1 = use AVETX, AVERX, HLAV
*                        2 = use terrain elevations (HI) to calculate HTE, HRE
2
* HTE, HRE:  Effective transmitter, receiver antenna heights above
*            average terrain elevations.  Used only for NTERR = 0.  (FT/M)
0  0
* HLEF(1:NOBS):  Effective diffraction obstacle heights above average terrain
*                elevation.  Used only for NTERR = 0.  (FT/M)
0  0
* AVETX, AVERX:  Transmitter, receiver average terrain elevations above
*                sea level.  Used only for NTERR = 1.  (FT/M)
3400  7135
* HLAV(1:NOBS):  Average terrain elevation above sea level at each
*                diffraction point.  Used only for NTERR = 1.  (FT/M)
7800  8500
* NPM(1:NOBS+1):  Number of terrain elevations between each pair of diffraction
*                 obstacles. (Tx and Rx are end points.) (default = 1,0,0,0)
9  9  9
* HI(1:NPM(1) + ... + NPM(NOBS+1)):  Terrain elevation data beginning with
*       transmit site elevation and ending with receive site elevation (FT/M)
4822.82  3535  3500  3485  3200  4160  4500  5000  9128
9128  7250  7100  7250  7500  8000  8150  8000  9454
9454  5800  5700  5600  5650  5500  5400  5500  7135.81
DIVERSITY DATA INPUT SECTION -- * -- * -- * -- * -- * -- * -- * -- * -- * --
* DIVTYP:  Diversity Type (default = 0)
*       0 = 2S      2S/2F        2S/2A   2S/2A/2F
*       1 = 2A      2F           2F/2A
*       2 = 2S/2P   2S/2P/2A
*     S = Space  F = Frequency  A = Angle  P = Polarization
```

TROPO.DAT for RUN 4 (continued)

```
1
* TDIAM:  Transmitter antenna aperture diameter (AT(1)) (FT/M)
88.58
* RDIAM:  Receiver antenna aperture diameter (AR(1)) (FT/M)
88.58
* TELH:  Transmitter antenna beam elevation above horizon (PSITEO(1)).  Input
*        an angle 4000 or greater to have TELH calculated.  (DEG/MRAD)
4000
* RELH:  Receiver antenna beam elevation above horizon (PSIREO(1)).  Input
*        an angle 4000 or greater to have RELH calculated.  (DEG/MRAD)
.27
* PHDIV:  Angle between upper and lower beams (Default = Beamwidth) (DEG/MRAD)
0.0
* TFLAG, TSEP:  TFLAG = Transmitter antenna spacing indicator
*               (TFLAG must be 0 for this version of TROPO.)
*               TSEP = Transmitter antenna separation (FT/M)
0  200
* RFLAG, RSEP:  RFLAG = Receiver antenna spacing indicator
*               (RFLAG must be 0 for this version of TROPO.)
*               RSEP = Receiver antenna separation (FT/M)
0  200
PROPAGATION DATA INPUT SECTION -- * -- * -- * -- * -- * -- * -- * -- * -- * --
* SEAN:  Refractivity at sea level (default = 0)
0
* ERFAC:  Effective Earth Radius Factor, K.  Recalculated if SEAN > 0.
*         (default = 1.33)
1.33
* SCPARM:  Wavenumber Spectrum Slope Parameter M for atmospheric turbulence.
*          Reset to 5 if Frequency < 1GHz.  (default = 3.66)
3.66
* NACCU, ERR:  Integration accuracy (truncation point) and resolution.
*              (defaults = 40, 0.001)
40  .001
* TAPOUT:  Enter T to have simulator tap values output in FOR002.DAT (default),
*          enter F to suppress the calculations and output.
F
* SPE, MLAST:  Simulator tap spacing in nanoseconds and
*              number of taps (defaults = 67 nsec, 16)
67  16
* KPROF.  Number of CN2 profile samples.  Maximum = NPROF  (See TROPAR.INC)
0
* HLOW,DELH:  Lowest height above sea level at which CN2 is specified (FT/M),
*             Spacing of CN2 samples (FT/M)
0  0
* CN2(KPROF):  The atmospheric structure constant height profile samples (FT/M)
0
MODEM INPUT SECTION -- * -- * -- * -- Data for MODPAT > 0 * -- * -- * -- * -- *
* IBW:  Bandwidth constraint indicator (default = 0)
*       0 = No filter, 1 = 99%, 2 = FCC-19311, 3 = user specified
1
* IFILTX,IFILRX:  Transmit, receive filter impulse response (For IBW = 3 only):
*               0 = MD-918 filter for receiver or transmitter
*               1 = AN/TRC-170 filter for transmitter (not used for receiver)
*               2 = AN/TRC-170 filter for receiver (not used for transmitter)
0  0
* FCTX,FCRX:  Transmitter, receiver 3dB cut-off frequencies (For IBW = 3 only)
*             (MHZ only)
0  0
```

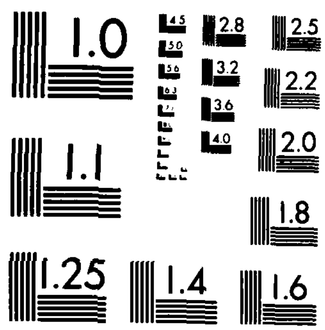
AD-A151 418 DIGITAL TROPOSCATTER PERFORMANCE MODEL USERS MANUAL(U) 4/4
SIGNATRON INC LEXINGTON MA P MONSEN ET AL. NOV 83
A-288-15 DCA100-80-C-0030

UNCLASSIFIED F/G 17/2.1 NL

END

FILMED

DTIC


1.0
1.1
1.25
1.4
1.6
1.8
2.0
2.2
2.5
2.8
3.2
3.6
4.0

```
* NPOLTX,NPOLRX:  Number of transmitter, receiver poles of Butterworth filter
*                 (For IBW = 3 only)
0  0
* BW:  Bandwidth, (default = 7.0 MHz)  (MHZ only)
7.0
* DRATE:  Data rate (bits/second)  (default = 6.6E6 bits/second)
2.3E6
* NERT:  Bit error rate threshold indicator:
*        0 = all, 1 = 1.0E-3, 2 = 1.0E-4 (default), 3 = 1.0E-5
0
MD-918 MODEM INPUT SECTION -- * -- * -- * -- Data for MODPAT = 1 * -- * -- * --
* TAPW:  Normalized tap width.  Range = 0.25 through 1.0.  (default = .5)
.5
* LISI:  Number of future ISI contributors considered  (default = 2)
2
AN/TRC-170 MODEM INPUT SECTION -- * -- * -- Data for MODPAT = 2 * -- * -- * --
* TRCTYP:  0 = single frequency, DAR modem;
*          1 = two frequencies, AN/TRC-170 modem (default)
1.0
INTERFERENCE PARAMETER INPUT SECTION -- * -- * -- * -- * -- * -- * -- * --
* JPOW:  Interference Power Density (default = -1000dBm/Hz for no interference)
-1000.
* JBW:  99% Interference Bandwidth (default = Bandwidth BW) (MHZ only)
10.5
* FJSEP:  Frequency separation between the interference signal and desired
*         signal (default = larger of BW and JBW) (MHZ only):
*               0.  = co-channel interference
*               > BW and JBW = adjacent channel interference
21.0
* MANG:  Number of interferer azimuth, elevation pairs (default = 1)
5
* (XANG(I), ELANG(I),I=1,MANG):  Interferer azimuth, elevation angle (above
*        horizon) pairs.  (default = 0,0)  (DEG/MRAD)
.05  0  32.  0  8.  0  2.  0  .05 0
* MODSIG:  Interfering signal modulation format; 0 = FDM/FM, 1 = QPSK (default)
1
USER-SUPPLIED DIVERSITY INPUT SECTION -- * -- * -- * -- * -- * -- * -- * --
* NT, NR:  Number of transmit and receive ports;  Maximums = NTMX, NRMX
1  2
* AT(NT):  Transmitter antenna aperture diameter (FT/M)
28
* AR(NR):  Receiver antenna aperture diameter (FT/M)
2*30
* PSITEO(NT):  Transmitter beam elevation above horizon (DEG/MRAD)
4000
* PSIREO(NR):  Receiver beam elevation above horizon (DEG/MRAD)
2*.33966
* PSITAO(NT):  Transmitter beam azimuth (DEG/MRAD)
0
* PSIRAO(NR):  Receiver beam azimuth (DEG/MRAD)
0.  0.
* IPOLT(NT):  Transmitter polarizations (DEG/MRAD)
0
* IPOLR(NR):  Receiver polarizations (DEG/MRAD)
0  0
* ((IBR(I,J),J=I,NR),I=1,NR):  Beams and cross-beams at receiver.
*       Enter:  0 = correlation between receivers I and J is not desired
*               1 = only power (correlation) calculations are desired
```

TROPO.DAT for RUN 4 (concluded)

```
*               2 = power (correlation) per unit delay calculations are desired
2  2  2
* UTH(NT):  Transmitter horizontal offsets (FT/M)
0
* UTV(NT):  Transmitter vertical offsets (FT/M)
0
* UTL(NT):  Transmitter longitudinal offsets (FT/M)
0
* URH(NR):  Receiver horizontal offsets (FT/M)
0  0
* URV(NR):  Receiver vertical offsets (FT/M)
0  0
* URL(NR):  Receiver longitudinal offsets (FT/M)
0  0
END
```

***** Ignoring PSITEO and PSIREO input. Calculating angles.

FOR002.DAT for RUN 4

```
*** INPUT PARAMETERS *** 15-NOV-83  23:14:38

                                                          << OUTDAT>>

                         PATH PARAMETERS
                         ---------------

LINK NAME (LNAME): RUN 4: TROPO - AN/TRC-170

PATH/MODEM INDICATOR (MODPAT):      2
  0 = Path only
  1 = Path + MD-918 modem
  2 = Path + AN/TRC-170 or DAR modem
  3 = Path + user defined modem

CLIMATE CLASS (ICLIME):             1
  0 = NBS TN101 CLIMATE
  1 = MIL-HDBK-417 CLIMATE
  2 = NEW USER-SUPPLIED CLIMATE

CLIMATE (CLIMAT):     CT

 NBS CLIMATES:
   CT   = CONTINENTAL TEMPERATE
   MTL  = MARITIME TEMPERATE OVERLAND
   MTS  = MARITIME TEMPERATE OVERSEA
   MSL  = MARITIME SUBTROPICAL OVERLAND
   CT2  = CONTINENTAL TEMPERATE TIME BLOCK 2
   DS   = DESERT, SAHARA
   EQU  = EQUATORIAL
   CS   = CONTINENTAL SUBTROPIC
   CTD  = MIXED CLIMATES - CT AND DS
   MTLD = MIXED CLIMATES - MTL AND DS

 MIL-HDBK-417 CLIMATES:
   CT   = CONTINENTAL TEMPERATE
   MTL  = MARITIME TEMPERATE OVERLAND
   MTS  = MARITIME TEMPERATE OVERSEA
   MS   = MARITIME SUBTROPICAL
   DS   = DESERT, SAHARA
   EQU  = EQUATORIAL
   CS   = CONTINENTAL SUBTROPICAL
   MED  = MEDITERRANEAN
   POL  = POLAR

I/O UNITS INDICATOR (LUNITS):  8 = smi  ft   deg  GHz
   0 = smi ft  mrad GHz
   1 = km  m   mrad GHz
   2 = nmi ft  mrad GHz
   8 = smi ft  deg  GHz
   9 = km  m   deg  GHz
  10 = nmi ft  deg  GHz
  16 = smi ft  mrad MHz
  17 = km  m   mrad MHz
  18 = nmi ft  mrad MHz
  24 = smi ft  deg  MHz
  25 = km  m   deg  MHz
```

FOR002.DAT for RUN 4 (continued)

```
26 = nmi ft  deg  MHz
```

FOR002.DAT for RUN 4 (continued)

```
EVENLY SPACED TERRAIN ELEVATION ABOVE SEA LEVEL DATA IN ft
        NP1 =  9                 NP2 =  9
  TX - RADIO HORIZON        RADIO HORIZON - RX
        HI(1: 9)                 HI(10:18)
       4822.82                  9454.00
       3535.00                  5800.00
       3500.00                  5700.00
       3485.00                  5600.00
       3200.00                  5650.00
       4160.00                  5500.00
       4500.00                  5400.00
       5000.00                  5500.00
       9128.00                  7135.81

DIVERSITY TYPE (DIVTYP):                              1
  0 = DIVERSITY OPTIONS:
      2S/2F, 2S, 2S/2A, 2S/2A/2F
  1 = DIVERSITY OPTIONS:
      2A, 2F, 2F/2A
  2 = DIVERSITY OPTIONS:
      2S/2P, 2S/2P/2A
  S = SPACE F = FREQUENCY A = ANGLE P = POLARIZATION

NUMBER OF TRANSMIT PORTS (NT):                        1
NUMBER OF RECEIVE PORTS  (NR):                        2

TRANSMIT ANTENNA DIAMETER (AT): PORT 1               88.58 ft

RECEIVE ANTENNA DIAMETER (AR):  PORT 1               88.58 ft
RECEIVE ANTENNA DIAMETER (AR):  PORT 2               88.58 ft

ANTENNA BORESIGHT ELEVATION ABOVE REFERENCE HORIZON
  TRANSMIT (PSITEO): PORT 1                           0.2258 deg   --> Angle calculated

  RECEIVE  (PSIREO): PORT 1                           0.2258 deg   --> Angle calculated
  RECEIVE  (PSIREO): PORT 2                           1.3547 deg   --> Angle calculated

ANTENNA BORESIGHT AZIMUTH, DEFINES
THE ANGLE TO THE GREAT-CIRCLE PLANE
 POSITIVE COUNTER-CLOCKWISE FOR TRANSMIT
 POSITIVE CLOCKWISE FOR RECEIVE
  TRANSMIT (PSITAO): PORT 1                           0.0000 deg

  RECEIVE  (PSIRAO): PORT 1                           0.0000 deg
  RECEIVE  (PSIRAO): PORT 2                           0.0000 deg

POLARIZATIONS
  TRANSMIT (IPOLT): PORT 1                            0

  RECEIVE  (IPOLR): PORT 1                            0
  RECEIVE  (IPOLR): PORT 2                            0

ANGLE BETWEEN UPPER AND LOWER BEAM (PHDIV):           1.1289 deg

BEAM AND CROSS-CORRELATION BEAM INDICATORS
  0 = NO CALCULATION
  1 = POWER (CORRELATION) ONLY
  2 = DELAY (CROSS) POWER SPECTRUM
```

FOR002.DAT for RUN 4 (continued)

```
TRANSMIT POWER (PXMIT):                                  50.00 dBm
TRANSMIT POWER (WLT):                                   100.00 W

FREQUENCY (F):                                            0.87 GHz

SERVICE PROBABILITY (SP):                                 0.950
NOISE FIGURE (NFIG):                                      4.00 dB

TRANSMITTER LINE LOSS (TLL):                              1.50 dB
RECEIVER LINE LOSS (RLL):                                 1.50 dB

TERMINAL DISTANCE (D):                                  178.30 smi

SITE ELEVATION ABOVE SEA LEVEL:
  TRANSMITTER (HTO)                                    4822.82 ft
  RECEIVER    (HRO)                                    7135.81 ft

ANTENNA HEIGHT ABOVE GROUND:
  TRANSMITTER (HT)                                       55.00 ft
  RECEIVER    (HR)                                       55.00 ft

ANTENNA HEIGHTS ABOVE SEA LEVEL:
  TX HTS=HTO+HT                                        4877.82 ft
  RX HRS=HRO+HR                                        7190.81 ft

PATH CALCULATION INDICATOR (PTYPE):                       0
  0 = TROPOSCATTER ONLY
  1 = MIXED TROPOSCATTER-DIFFRACTION OR DIFFRACTION ONLY
      PTYPE = 10 OR 11 EQUIVALENT TO PTYPE = 0 OR 1
      WITH POWER VS DELAY PROFILE OUTPUT SUPPRESSED

TAKE-OFF ANGLES CALCULATION INDICATOR (ITOFF):            2
   0 = SPECIFIED IN INPUT
   1 = CALCULATED USING K (ERFAC) = 1.33
   2 = CALCULATED USING INPUT SPECIFIED K (ERFAC) VALUE
   3 = UNCHANGED FROM PREVIOUS VALUE

DISTANCE TO HORIZON, MEASURED AT SEA LEVEL
  TRANSMITTER (DLT):                                     88.00 smi
  RECEIVER (DLR):                                        33.30 smi

HEIGHT ABOVE SEA LEVEL OF
  TRANSMIT HORIZON OBSTACLE (HLT):                     9128.00 ft
  RECEIVE HORIZON OBSTACLE (HLR):                      9454.00 ft

HTE, HRE DATA INDICATOR (NTERR):                          2
  0 = USER-SUPPLIED
  1 = AVETX, AVERX DATA
  2 = TERRAIN ELEVATION DATA
```

FOR002.DAT for RUN 4 (continued)

```
IBR(1,1)  =  2
IBR(1,2)  =  2
IBR(2,2)  =  2
```

TRANSMITTER OFFSETS (RELATIVE LOCATION)

	HORIZONTAL (UTH)	VERTICAL (UTV)	LONGITUDINAL (UTL)
PORT 1	0.00 ft	55.00 ft	0.00 ft

RECEIVER OFFSETS (RELATIVE LOCATION)

	HORIZONTAL (URH)	VERTICAL (URV)	LONGITUDINAL (URL)
PORT 1	0.00 ft	55.00 ft	0.00 ft
PORT 2	0.00 ft	55.00 ft	0.00 ft

EFFECTIVE EARTH RADIUS FACTOR K (ERFAC):	1.3300
WAVENUMBER SPECTRUM SLOPE PARAMETER M (SCPARM):	5.00
PARAMETER FOR TERMINATION OF NUMERICAL INTEGRATION (NACCU)	40
INTEGRATION RESOLUTION (ERR):	0.0010

MODEM PARAMETERS

```
RF BANDWIDTH CONSTRAINT (IBW):                          1
  0 = NO FILTER
  1 = 99% BANDWIDTH CONSTRAINT
  2 = FCC-19311 BANDWIDTH CONSTRAINT
  3 = USER-SPECIFIED TX AND RX FILTERS

BANDWIDTH (BW):                                         7.00 MHz
DATA RATE (DRATE):                                      2.3000 Mbits/sec

MODEM TYPE (MODPAT):                                    2
  1 = MD-918
  2 = AN/TRC-170 or DAR
  3 = User defined
```

DAR MODEM PARAMETERS

```
DAR/TRC MODEM TYPE (TRCTYP):                            1.0
 0.0 = SINGLE FREQUENCY DAR
 1.0 = 2 FREQUENCY TRC-170

ERROR RATE THRESHOLD INDICATOR (NERT):                  0
  0 = ALL (1.0E-3 1.0E-4 1.0E-5)
  1 = 1.0E-3
  2 = 1.0E-4
  3 = 1.0E-5
```

INTERFERENCE PARAMETERS

```
  INTERFERENCE POWER DENSITY (JPOW):                -1000.00 dBm/Hz
    (FOR NO INTERFERENCE, DENSITY IS -1000dBm/Hz)

  99% INTERFERENCE BANDWIDTH (JBW):                    10.50 MHz

  FREQUENCY SEPARATION BETWEEN
  SYSTEM AND INTERFERENCE (FJSEP):                     21.00 MHz

  INTERFERENCE SIGNAL MODULATION (MODSIG):              1
  (0 = FDM/FM, 1 = QPSK)
```

FOR002.DAT for RUN 4 (continued)

TROPOSCATTER PROPAGATION OUTPUT PARAMETERS: SECTION 1

<< POWER>>

```
ATMOSPHERIC ABSORPTION LOSS (AA):                      1.304 dB
TRANSMIT BEAMWIDTH (BWT):                              0.9031 deg
RECEIVE BEAMWIDTH  (BWR):                              0.9031 deg

NUMBER OF INTEGRATION CELLS (ITER):                 3352

LONG TERM REFERENCE TROPOSCATTER PATH LOSS,
NO CLIMATE CORRECTION

REFERENCE PATH LOSS ON LOWER BEAM (TEMP1):           228.97 dB
REFERENCE PATH LOSS ON UPPER BEAM (TEMP2):           234.56 dB
CORRELATION COEFFICIENT BETWEEN LOWER AND
UPPER BEAM (RH1):                                      0.0417

APERTURE-TO-MEDIUM COUPLING LOSS (CPL): BEAM 1 1      11.39 dB
APERTURE-TO-MEDIUM COUPLING LOSS (CPL): BEAM 2 2      13.78 dB

CORRELATION COEFF FOR LONG TERM VARIABILITY (CORRLT): 0.735910E+00

RELATIVE AVERAGE DELAY OF LOWER BEAM (DEL1)          329.9 nsec
RELATIVE AVERAGE DELAY OF UPPER BEAM (DEL2)          471.2 nsec

2*SIGMA DELAY SPREAD LOWER BEAM (TAU22):             132.3 nsec
2*SIGMA DELAY SPREAD UPPER BEAM (TAU23):             202.6 nsec

ESTIMATED MAXIMUM DELAY SPREAD LOWER BEAM (TEMP1):   313.4 nsec

Tx RADIO HORIXON ELEVATION ANGLE (THET) =              7.85556E-04 rad
Rx RADIO HORIXON ELEVATION ANGLE (THER) =              9.70620E-03 rad

Tx SITE AVERAGE TERRAIN ELEVATIONS (AVETX) =         884.36 m
Rx SITE AVERAGE TERRAIN ELEVATIONS (AVERX) =        1635.03 m

EFFECTIVE TRANSMITTER HEIGHT (HTE) =                 602.36 m
EFFECTIVE RECEIVER HEIGHT (HRE) =                    556.63 m

EFFECTIVE DISTANCE (DE):                             181.18 km
MEDIAN CLIMATE CORRECTION FACTOR (VDE) =               3.543 dB

  VARIABILITY DISTRIBUTION YO(QT,DE)

        100 QT%          YO(QT,DE)
          0.01             40.284
          0.10             33.025
          1.00             24.194
         10.00             12.097
         90.00             -9.804
         99.00            -17.843
         99.90            -23.628
         99.99            -28.431
```

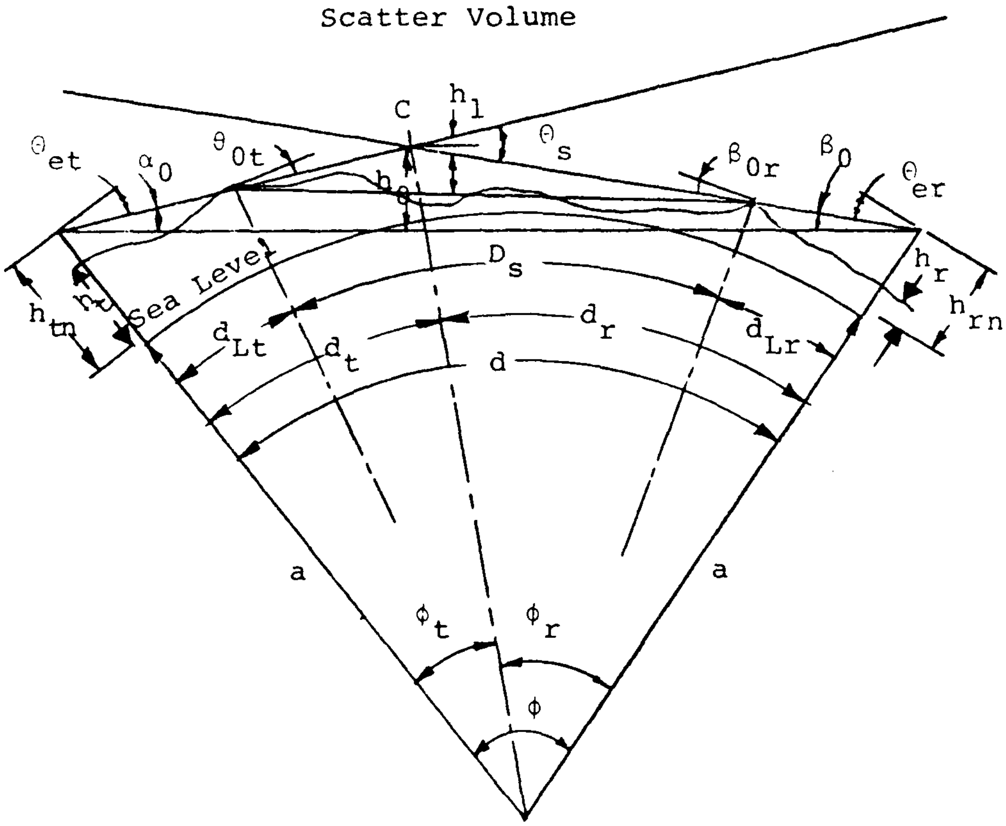
FOR002.DAT for RUN 4 (continued)

YEARLY DISTRIBUTION OF SHORT-TERM MEAN Eb/No

SERVICE PROBABILITY (SP) = 0.950

MEDIAN OF SHORT-TERM MEAN Eb/No (ASNR) 1.5729E+01
STANDARD DEVIATION (STSNR) 1.0509E+01
MEDIAN PATHLOSS (PMED) 231.32

PERCENTILE (NOT EXCEEDED) (TEMP1)	PATH LOSS (dB) (TLOSS)	RSL (dBm) (RSL)	MEAN Eb/No (SNR)
0.01	208.910	-69.849	38.134
0.10	212.176	-73.115	34.868
1.00	216.264	-77.202	30.780
10.00	222.412	-83.351	24.632
50.00	231.315	-92.254	15.729
90.00	243.360	-104.299	3.684
99.00	255.047	-115.986	-8.003
99.90	263.788	-124.727	-16.744
99.99	271.144	-132.083	-24.100



$$\theta_s = \frac{d}{a} + \theta_{et} + \theta_{er}$$

Figure A-1 Path Geometry - Great Circle View

A.1 PATH GEOMETRY

Figure A-1 shows the geometry of the path as seen in the plane of the great circle through the nominal antenna locations. Figure A-2 shows a top view of a path with horizontally spaced antennas. The parameters in Figure A-1 are those used in most troposcatter calculations, such as in NBS Tech. Note 101. In addition to these parameters we must also consider:

1. location of space diversity antennas relative to the nominal terminal location,

2. angle diversity beams.

The key TROPO program parameters including the effective earth radius transformation are listed below.

NBS TECH. NOTE SYMBOL	TROPO SYMBOL	
a_0	[A0]	Earth radius.
a	[A]	Effective earth radius.
d	[D]	Distance between nominal terminal locations.
d_{Lt}	[DLT]	Distance to horizon from the transmitter, measured at sea level.
d_{Lr}	[DLR]	Distance to horizon from the receiver (measured at sea level).

APPENDIX A

DEFINITION OF MATHEMATICAL AND COMPUTER PROGRAM SYMBOLS USED IN THE TROPOSCATTER PROPAGATION MODEL

This appendix contains the mathematical symbols used and the corresponding computer program parameters. The symbols are described in the context of the COMMON statement in which they appear in the computer program. When variable dimensions are used these appear in a PARAMETER statement. The variables defined this way are:

NTMX	=	Maximum number of distinct transmitter ports.
MRMX	=	Maximum number of distinct receiver ports.
NCORMX	=	Maximum number of diversity power and cross-correlation calculations allowed.
NDELMX	=	Maximum number of delay cells for the power per unit delay and correlation per unit delay profiles.
NPROF	=	Number of samples of C_n^2 profile allowed.

In what follows, the symbols used in the computer code are listed in square brackets.

SUMPAG.OUT for RUN 4 (concluded)

```
     TROPOSCATTER PATH CALCULATIONS

        Tx Site - Rx Site
        RUN 4: TROPO - AN/TRC-170                    Page  3

Auxiliary data

LUNITS= 8 (smi -ft  -deg -GHz )

Desired receive beam correlations:
             11: prof
             12: prof
             22: prof

Theoretical reference path loss :     229.19 dB

Horizon dist.&elev.(AMSL):  88.0 smi 9127.5 ft       33.3 smi 9453.5 ft

Eff. earth radius factor= 1.33 Spectrum slope= 5.00

Integration resolution params. ERR=  0.001000 NACCU=   40

Height of top of common volume HHIGH =      20645.8 ft
Height of bottom of common volume HCOM =    12226.1 ft
No. of cells in integration =  3352
```

SUMPAG.OUT for RUN 4 (continued)

TROPOSCATTER PATH CALCULATIONS

Tx Site - Rx Site
RUN 4: TROPO - AN/TRC-170 Page 2

Modem Type: AN/TRC-170 DAR

DIVERSITY 2S/2F
CONFIGURATION

Average Yearly Fade Outage Probability
@1.0E-4 BER 3.48E-01

Yearly Fade Outage Per Call Minute Probability (YFOP)
YFOP(@1.0E-4 BER) 5.80E-01

SUMPAG.OUT for RUN 4

```
TROPOSCATTER PATH CALCULATIONS      15-NOV-83  23:14:38

   Tx Site - Rx Site
   RUN 4:  TROPO - AN/TRC-170                         Page  1

                                  Tx Site        Rx Site

Site Elevations (AMSL):         4822.7 ft       7135.5 ft
Horizon T.O. Angles:              0.05 deg        0.56 deg
Antenna heights (AGL):           55.0 ft         55.0 ft
Antenna diameters:               88.6 ft         88.6 ft

Climate Type:   MIL-HDBK-417 CT

Freq.:     0.9 GHz ; Pathlength:  178.3 smi
Scat. ang.:  2.54 deg
Path asymmetry  s =  0.87deg /  1.67deg  =  0.5247

Transmit power:  100.0 W  ;  BW:     7.0 MHz

Line losses:  3.00 dB.   Atm. Abs. loss:  1.30dB

Beam   2-sigma del.spr.   Pathloss   RSL   (Reference values)

  1      132.3nsec        229.0 dB   -89.9 dBm
  2      202.6nsec        234.6 dB   -95.5 dBm

Correl.12: 0.0417   Receiver elevation angle diversity correlation
                     (El. Squint =   1.13 deg )
Min freq. separation required for freq div. [MHz] =     9.945

Correlation or coherence bandwith [MHz] =     2.945

   TROPOSCATTER PATH LOSS LONG TERM DISTRIBUTION

                   50%        99%       99.99%
Path Loss(dB)    231.32     255.05     271.14
RSL(dBm)         -92.25    -115.99    -132.08

Standard deviation of troposcatter path loss distribution:  10.509dB

Effective path distance:    181.18km
```

TROPO COMPLETED: 15-NOV-83 23:30:18

16.00	3.70	1.00E-03	2.4043E-04	2.8815E-03
16.00	3.70	1.00E-04	1.2075E-03	1.4394E-02
16.00	3.70	1.00E-05	3.5945E-03	4.2291E-02
18.00	3.71	1.00E-03	4.4761E-05	5.3704E-04
18.00	3.71	1.00E-04	1.1365E-04	1.3632E-03
18.00	3.71	1.00E-05	4.4823E-04	5.3657E-03
20.00	3.73	1.00E-03	2.3907E-06	2.8610E-05
20.00	3.73	1.00E-04	1.3266E-05	1.5950E-04
20.00	3.73	1.00E-05	4.4761E-05	5.3704E-04
22.00	3.76	1.00E-03	1.4567E-07	1.4305E-06
22.00	3.76	1.00E-04	2.3907E-06	2.8610E-05
22.00	3.76	1.00E-05	2.3907E-06	2.8610E-05
24.00	3.79	1.00E-03	1.1685E-10	0.0000E-01
24.00	3.79	1.00E-04	1.4567E-07	1.4305E-06
24.00	3.79	1.00E-05	1.4567E-07	1.4305E-06
28.00	3.95	1.00E-03	9.8921E-11	0.0000E-01
28.00	3.95	1.00E-04	1.1685E-10	0.0000E-01
28.00	3.95	1.00E-05	1.1685E-10	0.0000E-01

YEARLY FADE OUTAGE PROBABILITIES

AVERAGE FADE OUTAGE PROBABILITY

BER THRESHOLD (X)	2S OUTAGE (PYEAR(1,.))
1.00E-03	1.8780E-01
1.00E-04	2.2671E-01
1.00E-05	2.5916E-01

FADE OUTAGE PER CALL MINUTE

BER THRESHOLD (X)	2S OUTAGE (PYEAR(2,.))
1.00E-03	3.0999E-01
1.00E-04	3.6029E-01
1.00E-05	3.9985E-01

FOR002.DAT for RUN 4 (continued)

Eb/No (dB) (SNDB)	SNR LOSS (dB) (SNRLOS)	ERROR RATE THRESHOLD (X)	OUTAGE PROBABILITY (POUT)	FADE OUTAGE PER CALL MINUTE (POUT)
-6.00	3.69	1.00E-03	9.9196E-01	1.0000E+00
-6.00	3.69	1.00E-04	9.9196E-01	1.0000E+00
-6.00	3.69	1.00E-05	9.9196E-01	1.0000E+00
-4.00	3.69	1.00E-03	9.9196E-01	1.0000E+00
-4.00	3.69	1.00E-04	9.9196E-01	1.0000E+00
-4.00	3.69	1.00E-05	9.9196E-01	1.0000E+00
-2.00	3.69	1.00E-03	9.9196E-01	1.0000E+00
-2.00	3.69	1.00E-04	9.9196E-01	1.0000E+00
-2.00	3.69	1.00E-05	9.9196E-01	1.0000E+00
0.00	3.69	1.00E-03	9.9196E-01	1.0000E+00
0.00	3.69	1.00E-04	9.9196E-01	1.0000E+00
0.00	3.69	1.00E-05	9.9196E-01	1.0000E+00
2.00	3.69	1.00E-03	9.8603E-01	1.0000E+00
2.00	3.69	1.00E-04	9.9196E-01	1.0000E+00
2.00	3.69	1.00E-05	9.9196E-01	1.0000E+00
4.00	3.69	1.00E-03	8.6154E-01	1.0000E+00
4.00	3.69	1.00E-04	9.6782E-01	1.0000E+00
4.00	3.69	1.00E-05	9.9196E-01	1.0000E+00
6.00	3.69	1.00E-03	5.3512E-01	9.9990E-01
6.00	3.69	1.00E-04	7.7368E-01	1.0000E+00
6.00	3.69	1.00E-05	9.0323E-01	1.0000E+00
8.00	3.69	1.00E-03	2.1882E-01	9.4836E-01
8.00	3.69	1.00E-04	4.2053E-01	9.9857E-01
8.00	3.69	1.00E-05	6.0806E-01	9.9999E-01
10.00	3.69	1.00E-03	6.2213E-02	5.3735E-01
10.00	3.69	1.00E-04	1.5478E-01	8.6707E-01
10.00	3.69	1.00E-05	2.7659E-01	9.7946E-01
12.00	3.69	1.00E-03	1.2502E-02	1.4012E-01
12.00	3.69	1.00E-04	3.8912E-02	3.7891E-01
12.00	3.69	1.00E-05	8.3555E-02	6.4903E-01
14.00	3.70	1.00E-03	2.5982E-03	3.0736E-02
14.00	3.70	1.00E-04	8.0712E-03	9.2669E-02
14.00	3.70	1.00E-05	1.8245E-02	1.9825E-01

<< TRCIN>>

```
PULSE TYPE (IPULS) =                                       2
DURATION (CDUR) =                                          0.50
NUMBER OF CHIPS (NCHIP) =                                  1

SNR DEGRADATION DUE TO
PEAK POWER REQUIREMENTS (PEAKAV) =                         3.7065 dB
BANDWIDTH (BW99) =                                         7.0000 MHz
2*SIGMA MULTIPATH SPREAD/SYMBOL INTERVAL (X) =             0.0761
DIVERSITY CONFIGURATION :   2S or 2F
```

<< TRC>>

```
COMPUTED RANGE OF SAMPLING TIMES (TOTO)
-3.0068E-01 -2.5068E-01 -2.0068E-01 -1.5068E-01 -1.0068E-01
-5.0677E-02 -6.7735E-04

IMPLIED DIVERSITY EIGENVALUES (VEIGV)     0.9265E+00     0.2087E-01     0.7103E-03
```

SHORT TERM STATISTICS

Eb/No(dB) (SNRDB)	SNR LOSS(dB) (SNRLOS)	ABER (PAVG)
-6.00	3.69	3.3599E-01
-4.00	3.69	2.7249E-01
-2.00	3.69	1.9924E-01
0.00	3.69	1.2625E-01
2.00	3.69	6.6892E-02
4.00	3.69	2.8691E-02
6.00	3.69	9.7857E-03
8.00	3.69	2.6542E-03
10.00	3.69	5.7929E-04
12.00	3.69	1.0327E-04
14.00	3.70	1.5139E-05
16.00	3.70	1.8156E-06
18.00	3.71	1.7563E-07
20.00	3.73	1.3523E-08
22.00	3.76	8.2171E-10
24.00	3.79	3.5195E-11
28.00	3.95	1.1363E-13

FOR002.DAT for RUN 4 (continued)

16.00	3.70	1.00E-03	4.4240E-02	4.1898E-01
16.00	3.70	1.00E-04	8.8110E-02	6.6939E-01
16.00	3.70	1.00E-05	1.4018E-01	8.3674E-01
18.00	3.71	1.00E-03	2.1718E-02	2.3163E-01
18.00	3.71	1.00E-04	3.2180E-02	3.2464E-01
18.00	3.71	1.00E-05	5.7699E-02	5.0991E-01
20.00	3.73	1.00E-03	6.4544E-03	7.4762E-02
20.00	3.73	1.00E-04	1.3066E-02	1.4600E-01
20.00	3.73	1.00E-05	2.1718E-02	2.3163E-01
22.00	3.76	1.00E-03	2.1164E-03	2.5103E-02
22.00	3.76	1.00E-04	6.4544E-03	7.4762E-02
22.00	3.76	1.00E-05	6.4544E-03	7.4762E-02
24.00	3.79	1.00E-03	1.6982E-04	2.0360E-03
24.00	3.79	1.00E-04	2.1164E-03	2.5103E-02
24.00	3.79	1.00E-05	2.1164E-03	2.5103E-02
28.00	3.95	1.00E-03	1.2198E-04	1.4625E-03
28.00	3.95	1.00E-04	1.6982E-04	2.0360E-03
28.00	3.95	1.00E-05	1.6982E-04	2.0360E-03

YEARLY FADE OUTAGE PROBABILITIES

AVERAGE FADE OUTAGE PROBABILITY

BER THRESHOLD (X)	2S/2F OUTAGE (PYEAR(1,.))
1.00E-03	3.0102E-01
1.00E-04	3.4791E-01
1.00E-05	3.8552E-01

FADE OUTAGE PER CALL MINUTE

BER THRESHOLD (X)	2S/2F OUTAGE (PYEAR(2,.))
1.00E-03	5.2823E-01
1.00E-04	5.7976E-01
1.00E-05	6.1874E-01

FOR002.DAT for RUN 4 (continued)

Eb/No (dB) (SNDB)	SNR LOSS (dB) (SNRLOS)	ERROR RATE THRESHOLD (X)	OUTAGE PROBABILITY (POUT)	FADE OUTAGE PER CALL MINUTE (POUT)
-6.00	3.69	1.00E-03	9.8613E-01	1.0000E+00
-6.00	3.69	1.00E-04	9.8613E-01	1.0000E+00
-6.00	3.69	1.00E-05	9.8613E-01	1.0000E+00
-4.00	3.69	1.00E-03	9.8613E-01	1.0000E+00
-4.00	3.69	1.00E-04	9.8613E-01	1.0000E+00
-4.00	3.69	1.00E-05	9.8613E-01	1.0000E+00
-2.00	3.69	1.00E-03	9.8613E-01	1.0000E+00
-2.00	3.69	1.00E-04	9.8613E-01	1.0000E+00
-2.00	3.69	1.00E-05	9.8613E-01	1.0000E+00
0.00	3.69	1.00E-03	9.8613E-01	1.0000E+00
0.00	3.69	1.00E-04	9.8613E-01	1.0000E+00
0.00	3.69	1.00E-05	9.8613E-01	1.0000E+00
2.00	3.69	1.00E-03	9.8613E-01	1.0000E+00
2.00	3.69	1.00E-04	9.8613E-01	1.0000E+00
2.00	3.69	1.00E-05	9.8613E-01	1.0000E+00
4.00	3.69	1.00E-03	9.8369E-01	1.0000E+00
4.00	3.69	1.00E-04	9.8613E-01	1.0000E+00
4.00	3.69	1.00E-05	9.8613E-01	1.0000E+00
6.00	3.69	1.00E-03	8.9859E-01	1.0000E+00
6.00	3.69	1.00E-04	9.6802E-01	1.0000E+00
6.00	3.69	1.00E-05	9.8613E-01	1.0000E+00
8.00	3.69	1.00E-03	6.9804E-01	1.0000E+00
8.00	3.69	1.00E-04	8.4622E-01	1.0000E+00
8.00	3.69	1.00E-05	9.2463E-01	1.0000E+00
10.00	3.69	1.00E-03	4.4756E-01	9.9919E-01
10.00	3.69	1.00E-04	6.2238E-01	9.9999E-01
10.00	3.69	1.00E-05	7.5102E-01	1.0000E+00
12.00	3.69	1.00E-03	2.3626E-01	9.6062E-01
12.00	3.69	1.00E-04	3.7347E-01	9.9634E-01
12.00	3.69	1.00E-05	4.9976E-01	9.9975E-01
14.00	3.70	1.00E-03	1.2214E-01	7.9055E-01
14.00	3.70	1.00E-04	1.9703E-01	9.2815E-01
14.00	3.70	1.00E-05	2.7586E-01	9.7921E-01

AN/TRC-170 MODEM OUTPUT PARAMETERS: SECTION 2

MODEM = TRC-170: TWO FREQUENCIES PER DIVERSITY

<< TRCIN>>

PULSE TYPE (IPULS) = 2
DURATION (CDUR) = 0.50
NUMBER OF CHIPS (NCHIP) = 1

SNR DEGRADATION DUE TO
PEAK POWER REQUIREMENTS (PEAKAV) = 3.7065 dB
BANDWIDTH (BW99) = 7.0000 MHz
2*SIGMA MULTIPATH SPREAD/SYMBOL INTERVAL (X) = 0.0761
DIVERSITY CONFIGURATION : 2S/2F or 4S

<< TRC>>

COMPUTED RANGE OF SAMPLING TIMES (TOTO)
-3.0068E-01 -2.5068E-01 -2.0068E-01 -1.5068E-01 -1.0068E-01
-5.0677E-02 -6.7735E-04

IMPLIED DIVERSITY EIGENVALUES (VEIGV) 0.9265E+00 0.2087E-01 0.7103E-03

SHORT TERM STATISTICS

Eb/No(dB) (SNRDB)	SNR LOSS(dB) (SNRLOS)	ABER (PAVG)
-6.00	3.69	4.0804E-01
-4.00	3.69	3.6775E-01
-2.00	3.69	3.1475E-01
0.00	3.69	2.5099E-01
2.00	3.69	1.8260E-01
4.00	3.69	1.1970E-01
6.00	3.69	6.9883E-02
8.00	3.69	3.6382E-02
10.00	3.69	1.6996E-02
12.00	3.69	7.1731E-03
14.00	3.70	2.7437E-03
16.00	3.70	9.4840E-04
18.00	3.71	2.9473E-04
20.00	3.73	8.3357E-05
22.00	3.76	2.3128E-05
24.00	3.79	6.6048E-06
28.00	3.95	1.5637E-07

FOR002.DAT for RUN 4 (continued)

FILTER DATA

<< BUTFIL>>

	TRANSMITTER		RECEIVER	
Filter type	1	(IFILTX)	2	(IFILRX)
Poles	2	(NPOLTX)	6	(NPOLRX)
Cut-off freq (MHz)	1.72	(FCUT1)	1.72	(FCUT2)

TRANSMISSION BANDWIDTH (MHz) (FCUT) = 7.0000

FILTER TYPE REFERS TO THE RECTANGULAR SECTION
= 0: FULL SYMBOL INTERVAL DURATION
= 1: HALF SYMBOL INTERVAL DURATION
= 2: NO RECTANGULAR SECTION

PEAK-TO-AVERAGE POWER RATIO (dB) (PEAKAV) = 3.7065

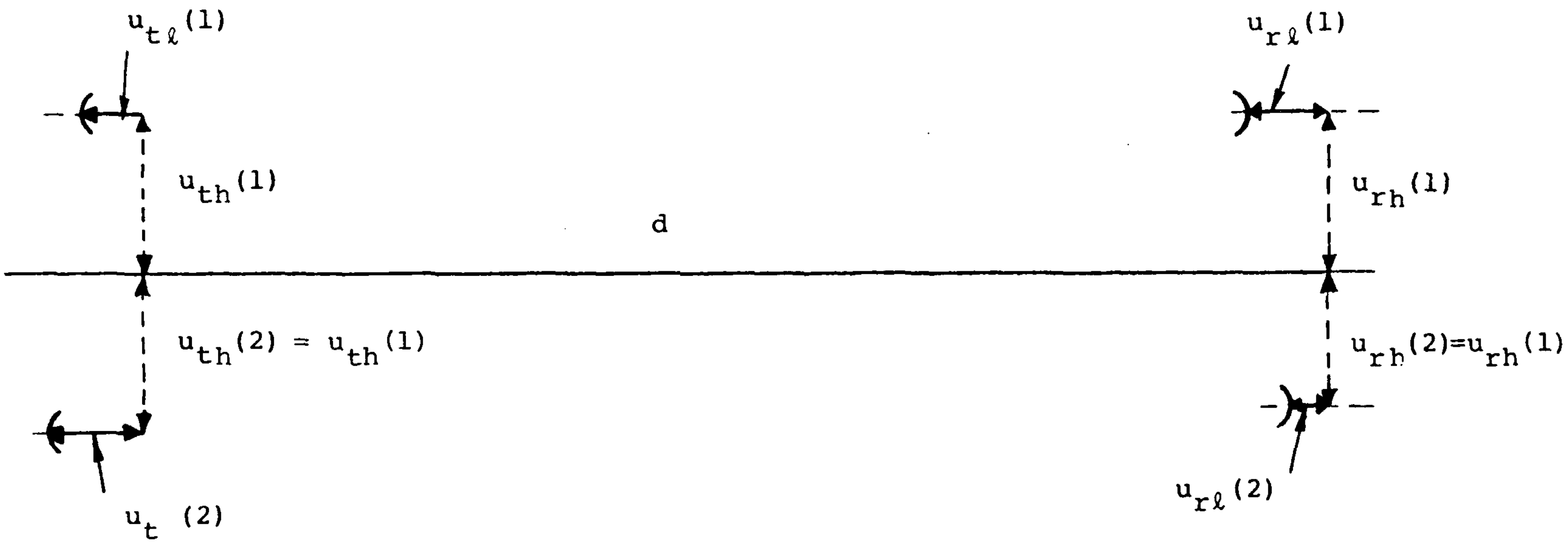


Figure A-2 Path Geometry - Top View

d_t	[DT]	Sea level distance to the scattering point from the nominal transmitter location.
d_r	[DR]	Sea level distance to the scattering point from the nominal receiver location.
h_{tn}	[HTO]	Height above the sea level of the nominal transmitter location.
h_{rn}	[HRO]	Height above the sea level of the nominal receiver location.
u_{th}, u_{tv}, $u_{t\ell}(i_t)$	[UTH(I), UTV(I) I<NTMX]	Horizontal, vertical, and longitudinal location of transmitting antenna number i_t relative to the nominal position (site ground level mid way between antennas) (counted positive up, into the paper, and from the transmitter to receiver respectively).
u_{rh}, u_{rv} $u_{r\ell}(i_r)$	[URH(I), URV(I), URL(I), I<NRMX]	Horizontal, vertical and longitudinal location of receiving antenna number if relative to the nominal position (site ground level mid way between antennas).

$h_t(i_t)$	[TXHTS]	Height above the sea level of the center of transmit antenna no. i_t, (=HTO + HT(i_t)).
$h_r(i_r)$	[RXHRS]	Height above the sea level of the center of receive antenna no. i_r, ($=h_{rn} + u_{rh}(i_r)$).
S	[S]	Asymmetry parameter α_0/β_0.
S_1	[S1]	Asymmetry parameter $(\alpha_0-\beta_0)/\Theta_0 = (1-S)/(1+S)$.
h_{Lt}, h_{Lr}	[HLT,HLR]	Height above the sea level of the transmit (receive) horizon obstacle.
h_0	[HCOM]	Height of lowest scattering point above sea level.
α_0	[ALFA0]	Angle at the nominal transmitter between the horizon ray and the ray to the receiver.
β_0	[BETA0]	Angle at the nominal receiver between the horizon ray and the ray to the nominal transmitter.
Θ_0	[THETA0]	Scattering angle.
ϕ_t	[PHIT]	d_t/a.
ϕ_r	[PHIR]	d_r/a.

Θ_{et}	[THET]	Transmitter horizon elevation angle.
Θ_{er}	[THER]	Receiver horizon elevation angle.

A.2 ANTENNA PARAMETERS

Parameters relating to the transmitter and receiver antennas are defined. Antenna location parameters are described in A.1.

A_t	[AT(I), $I < NT$]	Aperture diameter of transmit antennas,
A_r	[AR(I), $I < NR$]	and receive antennas.
$g_t(i_t, \psi)$	[TGAIN(I,PSI) $I < NT$]	Directive gain pattern of the transmitting aperture no. i_t. ψ is the angle relative to antenna boresight.
$g_r(i_r, \psi)$	[RGAIN(I,PSI) $I < NR$]	Receiver gain patterns.
$G_t(i_t)$	[GTDB(I), $I < NT$]	Transmitter antenna gains.
$G_r(i_r)$	[GRDB(I), $I < NR$]	Receiver antenna gains.

$\psi_{te0}(i_t)$	[PSITE0(I) I<NT]	Antenna boresight elevation above the horizon for each transmit antenna.
$\psi_{re0}(i_t)$	[PSIRE0(I) I<NR]	Same for receive antennas.
$\psi_{ta0}(i_t)$	[PSITA0(I) I<NT]	Transmit antenna boresight azimuth, defines the angle to the great-circle plane. Positive counter clockwise.
$\psi_{ra0}(i_r)$	[PSIRA0(I) I<NR]	Same for receiver, but positive clockwise.
N_t	[NT]	No. of distinct transmit ports.
N_r	[NR]	No. of distinct receive ports.

PROPAGATION PARAMETERS

AA	[AA]	Atmospheric dB attenuation.
K	[ERFAC]	Effective earth radius factor.
M	[SCPARM]	Wavenumber spectrum slope parameter.
N_s	[SEAN]	Minimum monthly medial value of sea level surface refractivity.

$C_n^2(ih)$	[CN2(I), I <NPROF]	Atmospheric structure constant profile.
Δ_h	[DELH]	Interval of sampled C_n^2.

SYSTEM TRANSMISSION PARAMETERS

	[LINKNO]	Link ID number.
	[LDIVID]	Diversity identifier.
	[LNAME(20)]	Link name.
	[LUNITS]	Link units.
$W_{\ell t}$	[WLT]	Transmitted power.
W_t	[WLT]	Radiated power.
W_r	[WR]	Available power at receiver input.
f	[F]	Frequency.
λ	[WAVLEN]	Wavelength.

$I_{Br}(N_r,N_r)$	[IBR(I,J), $I < NR, J < NR$]	Indicator of what calculation is desired for each beam and cross-correlation beam. IBR = 0: no calculation. IBR = 1: power (correlation) only desired. IBR = 2: delay (cross power spectrum.

APPENDIX B

DESCRIPTION OF MATHEMATICAL RESULTS USED IN THE TROPOSCATTER PREDICTION PROGRAM

This appendix contains the mathematical results used in the coding of the common volume integration routine. The correspondence of symbols to the variable names in the computer program are found in Appendix A.

B.1 THE EARTH RADIUS TRANSFORMATION

We use the well known effective earth radius concept in a way that allows an exact transformation.

Let a_0 be the actual earth radius (measured at sea level) and let r_0 be the distance from the center of the earth to any point on or above the surface of the earth. Propagation in a spherically stratified atmosphere is guided by the following equation

$$r_0 n(r_0) \sin \Theta_0(r_0) = a_0 n(a_0) \sin \Theta_0(a_0) \text{ (Snell's Law)} \tag{B.1}$$

and

$$r_0 d\phi_0 = \tan \Theta_0(r_0) dr_0 \tag{B.2}$$

where (see Figure B-1)

$\Theta_0(r_0)$ = zenith angle of ray at distance r_0

$\phi_0(r_0)$ = angle from start of path (at $r_0 = a$) to a variable point on the path.

We now assume a special form of height variation of the refractive index,

$$n(r_0) = n_0(a_0/r_0)^{\gamma} \quad . \tag{B.3}$$

The refractive index varies according to a power law. Near the surface of the earth the gradient is nearly constant. The refractive index varies with height in a way similar to that of the exponential model although the fall-off with increasing height is slower than for the exponential model. However the model in (B.3) is a better approximation than the linear gradient often assumed. The parameter γ is related to the gradient of the coefficient of refraction (expressed in N-units) by

$$\frac{\Delta N}{\text{N-units/km}} = -\gamma \cdot 10^9 \frac{n(a_0)}{a_0/[1m]} \quad . \tag{B.4}$$

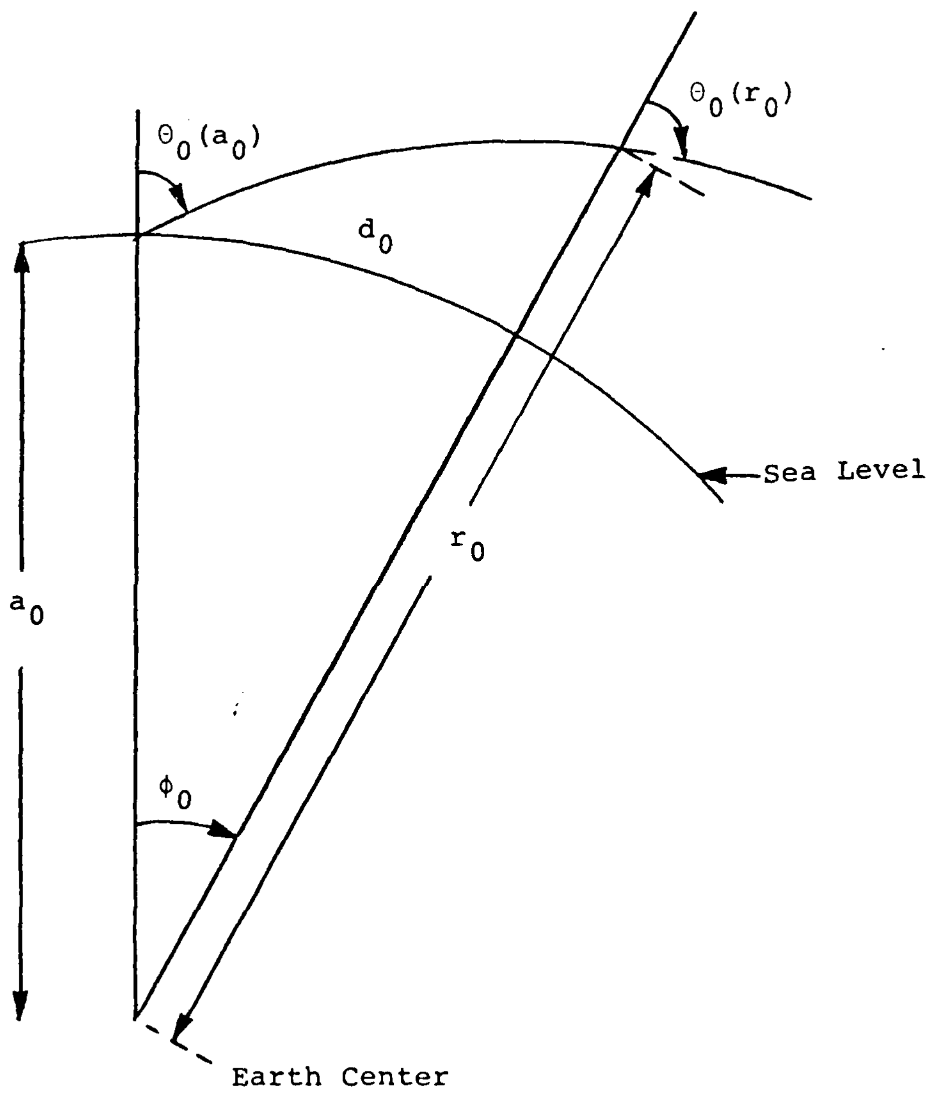


Fig. B-1 Path Geometry for Refractive Path

For the standard atmosphere we have $\gamma = 0.25$. The form of the refractive index in (B.3) allows us to transform the coordinates so that the electromagnetic waves propagate in straight lines in the transformed coordinate system. Define in the great circle plane

$$r = r(r_0) = \frac{1}{1-\gamma} a_0^{\gamma} r_0^{1-\gamma}$$

$$d = d_0 \quad . \tag{B.5}$$

This transformation preserves distance along the surface of the earth, but the new earth center distance r is different. In particular the new effective earth radius is

$$a = r(a_0) = a_0/(1-\gamma) \quad . \tag{B.6}$$

The angular distance ϕ_0 is transformed into

$$\phi = \delta_0(1-\gamma). \tag{B.7}$$

The angles Θ are preserved in the transformation,

$$\Theta(r,\phi) = \Theta_0(\Theta_0(r_0,\phi_0) \quad . \tag{B.8}$$

The transformation (B.5) when inserted into (B.1) and (B.2) shows that a path in the transformed coordinates satisfies

$$r \sin \Theta(r) = a \sin \Theta(a) \qquad \text{(B.1a)}$$

$$r \, d\phi = \tan \Theta(r) dr \qquad \text{(B.2a)}$$

which represents the equations for a straight line. Heights above the nominal sea level are transformed according to

$$a + h = \frac{1}{1-\gamma} a_0^{\gamma} (a_0 + h_0)^{1-\gamma}$$

or

$$h \simeq h_0 - \frac{\gamma}{2} \frac{h_0^2}{a_0} + \frac{\gamma(\gamma+1)}{3!} \frac{h_0^3}{a_0^2} \cdots \qquad \text{(B.9)}$$

This formula described the height reduction effect in a near linear profile of the refractive index. In practice only the first two terms are needed.

B.2 ANTENNA PATTERN, GAIN, AND BEAMWIDTH

Any type of antenna pattern may be used in the computer program by replacing or modifying the antenna subroutines. The default antenna patterns assume a parabolic dish with a 55% area efficiency. Let D be the diameter of the circular aperture. The gain is

$$G = \frac{6.4D^2}{\lambda^2} .$$

The 3dB beamwidth is

$$2\sigma = 70^0 \frac{\lambda}{D}$$

$$= 1.22 \frac{\lambda}{D} .$$

The following voltage beam pattern is assumed.

$$g(\Theta) = \frac{2J_1 \left(\frac{\pi D_e}{\lambda} \sin \Theta\right)}{\frac{\pi D_e}{\lambda} \sin \Theta}$$

$$D_e = D/1.2 .$$

To simplify the integration the pattern is truncated beyond the first sidelobe.

.3 CALCULATION OF SCATTERING POINT

The geometry for calculating the distances to and the ɜight of the scattering point is shown in Figure B-2. The disɜnces a_t is given by $a + h_{te}$, where h_{te} is the effective transitter height*. Let us place a coordinate system with origin at ıe center C and with X-axis along the line CR. Express in ɜctor coordinates the equation

$$\underline{CT} + \underline{TS} = \underline{CR} + \underline{RS} \quad ,$$

$$(a_t \cos \phi, a_t \sin \phi) + X_1 (\cos(\phi - 90^0 + \theta_{et}), \sin(\phi - 90^0 + \theta_{et}))$$

$$= (a_r, 0) + X_2 \, (\cos(90^0 - \theta_{er}), \sin(90^0 - \theta_{er}))$$

here X_1 and X_2 are unknowns. Solving for X_1 and X_2 we get

$$X_1 = [a_r \cos \theta_{er} - a_t \cos((\phi + \theta_{er})]/\sin \theta$$

$$X_2 = [a_t \cos \theta_{et} - a_r \cos(\phi + \theta_{et})]/\sin \theta \quad .$$

hese numbers should be positive if the input parameters are corect. The angle ϕ_r is determined from

$$\tan \phi_r = \frac{X_2 \cos \theta_{er}}{a_r + X_2 \sin \theta_{er}} \quad X_2/a_r \quad .$$

NOTE: This effective transmitter height is the height of the ransmitter above sea level plus the correction factor for ray ending (Eq. B.9) and should not be confused with the effective ransmit antenna height above average terrain elevation defined n Section 2.5.4 (E).

CALCULATION OF OFF-BORESIGHT ANGLES

Considering a scattering point (α, β, y) and a transmitter enna with

$$\psi_{te0} = \text{elevation above horizon}$$

$$\psi_{ta0} = \text{azimuth angle} \quad .$$

coordinate system centered at the transmitter the vector to scattering point is

$$\underline{v}_{ts} = (R_{0T} \cos, y, R_{0T} \sin \alpha) \quad ,$$

re

$$R_{0T} = d_0 \sin \beta / \sin (\alpha + \beta) \quad .$$

unit vector in the direction of the antenna beam is

$$\underline{v}_A = (\cos \psi_{ta0} \cos \alpha_A, \sin \psi_{ta0}, \cos \psi_{ta0} \sin \alpha_A)$$

$$\sin^2\Theta = 1 - \frac{(\underline{TS} \cdot \underline{RS})^2}{r_{ts}^2 \, r_{rs}^2}$$

this is found to reduce to

$$\sin^2\Theta = \frac{\left(\sin^2\Theta_1 + Q_\beta^2 - Q_\alpha^2 + 2 \cos \Theta_1 Q_\alpha Q_\beta\right)}{\left(1 + Q_\alpha^2\right) \left(1 + Q_\beta^2\right)}$$

where

$$\Theta_1 = \alpha + \beta$$

$$Q_\alpha = \frac{y \sin \Theta_1}{d_0 \sin \alpha} = y/R_{0R}$$

and

$$Q_\beta = \frac{y \sin \Theta_1}{d_0 \sin \beta} = y/R_{0T} \quad .$$

this point we note that the accuracy is actually required for the total path delay, and that we can write

$$r_{tsl} + r_{rsl} = d_0 + 2d_0 \frac{\sin\alpha/2 \sin\beta/2}{\cos(\alpha+\beta)/2} . \qquad (B.21)$$

Since the first term only contributes a constant delay it need not be evaluated. The overall path length is then described accurately by the sum of (B.21), (B.20), and the term analogous to (B.20) for the receiver.

For use in scattering angle calculations the distances r_{ts}, r_{rs} can be evaluated with sufficient accuracy using

$$r_{tsl} = d_0 \frac{\sin\beta}{\sin(\alpha+\beta)} .$$

B.6 CALCULATION OF SCATTERING ANGLE

It is assumed that, for each point in the scattering volume, the scattering angle to any pair of transmitter and receiver terminals is essentially the same. The scattering angle calculations here therefore refer to nominal transmit and receive antennas located in the great circle plane.

A point in the scattering volume is given by the coordinates (α,β,y). The scattering angle is the angle between the vectors $\underline{TS}$ (transmitter-to-scatterer) and the vector $\underline{SR}$ (scatterer-to-receiver). The length of these vectors are denoted r_{ts} and r_{rs}, respectively. The scattering angle Θ is evaluated from

$$\frac{2\pi}{\lambda}\left(r_{rsa} - r_{rsb}\right) \text{ or } \frac{2\pi}{\lambda}\left(r_{tsa} - r_{tsb}\right)$$

is much less than unity for two spaced antennas a and b. Write the vector $\underline{v}_{ts} = \underline{T}\,\underline{S}$ as

$$\underline{v}_{ts} = \underline{v}_{tsl} + \underline{u}_{tsl} \quad ,$$

where

$$\underline{v}_{tsl} = \left(R_{0t}\cos\alpha, 0 R_{0t}\sin\alpha\right)$$

$$\underline{u}_{tsl} = \left(-u_{t\ell y}, y-u_{th}, -u_{tv}\right) \quad .$$

Then, if

$$r_{ts} = \left|\underline{v}_{ts}\right| \ , \ r_{tsl} = \left|\underline{v}_{tsl}\right| \quad ,$$

$$r_{ts} - r_{tsl} = \frac{r_{ts}^2 - r_{tsl}^2}{r_{ts} + r_{tsl}} = \frac{2\underline{v}_{tsl}\,\underline{u}_{tsl} + \left|\underline{u}_{tsl}\right|^2}{\left|\underline{v}_{tsl} + \underline{u}_{tsl}\right| + \left|\underline{v}_{tsl}\right|} \quad . \qquad \text{(B.20)}$$

Calculation of r_{ts} relative to r_{tsl} in this way is much less susceptible to round off errors than a direct calculation of r_{ts}. This assumes that r_{tsl} is known with sufficient accuracy. At

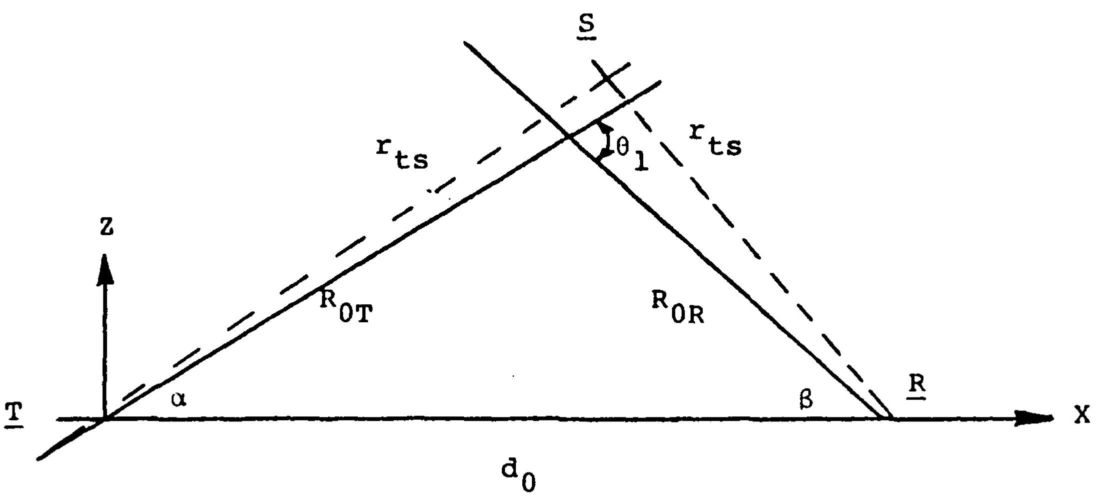


Figure B-4 Geometry for Distance Calculation

$$\underline{T} = (u_{t\ell}, u_{th}, u_{tv})$$

$$\underline{R} = (d_0 + u_{r\ell}, u_{rh}, u_{rv})$$

$$\underline{S} = (R_{0t} \cos \alpha, y, R_{0t} \sin \alpha)$$

$$= (d_0, 0, 0)$$

$$+ (-R_{0R} \cos \beta, y, R_{0R} \sin \beta)$$

where d_0 is the distance between nominal transmitter and receiver locations,

$$R_{0T} = d_0 \sin \beta / \sin \Theta_1$$

$$R_{0R} = d_0 \sin \alpha / \sin \Theta_1 \quad ,$$

($\Theta_1 = \alpha+\beta$), and the scattering point is determined by (α, β, y). The geometry is shown in Figure B-4. We wish to calculate the distances r_{ts}, r_{rs} to the scattering point with sufficient accuracy so that the variation of the differences in

or

$$\delta y < [A+y^2]^{1/2} - y \tag{B.19)a}$$

where

$$A = [(1-k)^{-2/m}-1]\ \theta^2(\alpha,\beta,y)R_0^2 \quad . \tag{B.19b}$$

Note that (B.16) and (B.19) allow a dynamic stepsize calculation since $\theta(\alpha,\beta,y)$ has to be evaluated at each point.

B.5 CALCULATION OF DISTANCES TO THE SCATTERING POINT

The distances are required to calculate the delay associated with each scattering point. In addition, they are needed to evaluate the cross correlations for space diversity antennas. For the latter application high accuracy is needed. Define a coordinate system centered at the nominal transmitter, X-axis along the line to the nominal receiver location, Z-axis up, and Y-axis perpendicular to the great circle plane. The transmitter, receiver, and scatterer (X,Y,Z) coordinates are

where

$$R_0 = \frac{d_t d_r}{d_t + d_r} \quad .$$

If we require that

$$\Theta^{-m}(\alpha, \beta, y) < \varepsilon\, \Theta^{-m}(\alpha, \beta, 0),$$

we get

$$|y_1| > R_0 \Theta(\alpha, \beta, 0) \left[\varepsilon^{-2/m} - 1 \right]^{1/2} \quad . \tag{B.18}$$

The step size in the y-direction is limited by the beamwidth through

$$\delta y < k \min\left(d_t \delta_{th}, d_r \delta_{rh} \right)$$

and by the scattering angle through

$$\Theta^{-m}(\alpha, \beta, y + \delta y) > (1-k)\Theta^{-m}(\alpha, \beta, y) \quad ,$$

The stepsizes must also satisfy

$$(\Theta+\delta\alpha)^{-m} > 0.8(\Theta)^{-m} \quad .$$

We use

$$\delta\alpha, \delta\beta < \Theta\left((1-k)^{-1/m}-1\right) \tag{B.16}$$

(B.14) through (B.16) determine the stepsizes (dependent on Θ). Now consider the integration in the y-axis direction perpendicular to the great circle plane. Let $\pm y_1$ be the extreme values of the integration. We must have

$$y_1 > \min\left(d_t \delta_{th}, d_r \delta_{rh}\right) \quad , \tag{B.17}$$

where δ_{th} and δ_{rh} are the combined horizontal semi beamwidths, including horizontal angle diversity offsets, if applicable. The maximum y-values may also be limited by the scattering angles. We assume here that the horizons are essentially straight horizontal obstacles so that α_{min} and β_{min} are unchanged for off-centerplane scattering. For present purposes we can use the following approximation to the scattering angle Θ,

$$\Theta^2(\alpha,\beta,y) = \Theta^2(\alpha,\beta,0) + \left(y/R_0\right)^2 \quad ,$$

or

$$\alpha_1 + \beta_1 > \epsilon_1^{\frac{1}{m-2}}(\alpha_m + \beta_m) \quad .$$

A weaker bound is then

$$\alpha_1 > \epsilon_1^{-1/(m-2)}(\alpha_m+\beta_m) - \beta_m \tag{B.12}$$

$$\beta_1 > \epsilon_1^{-1(m-2)}(\alpha_m+\beta_m) - \alpha_m \tag{B.13}$$

(B.10) through (B.13) determine the minimum and maximum angles. The value of ϵ_1 used is min (0.2, 50ϵ).

The stepsize in the angle integrations must be small enough so that the antenna patterns are not quantized too coarsely. Typically we must have

$$\delta\alpha < k\,\delta_t \tag{B.14}$$

$$\delta\beta < k\,\delta_r \tag{B.15}$$

where the constant k should be less than 0.2. To allow for the possibility of smaller step sizes use

$$k = 0.2 \min(1{,}000\epsilon) \ .$$

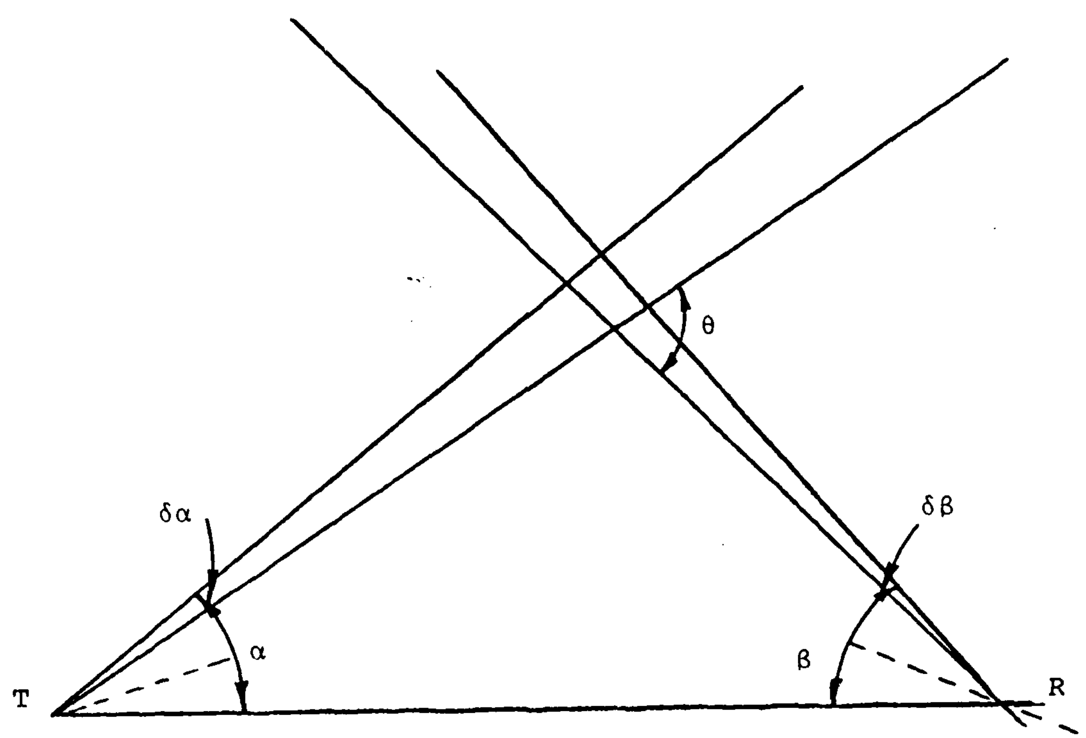


Figure B-3   Common Volume Integration in the Great Circle Plane

B.4 COMMON VOLUME CALCULATIONS

The size of the common volume is limited by the antenna size, pointing angles, scattering angle, and atmospheric structure constant. We have already determined the minimum angles α_0, β_0 of the angle α and β (see Figure B-3). In order to get an idea of the step size required in the common volume integration it is necessary to calculate the maximum angles α_1, β_1. The integration will be performed by integrating over α, β, and the distance y perpendicular into the paper. It is assumed that all transmitter beams are essentially pointed at the horizons. Let β_m be the β-angle corresponding to the most elevated receiving beam, and let α_m, Θ_m be the corresponding transmitter and scatter angles. We have

$$\alpha_1 - \alpha_m > \delta_t \tag{B.10}$$

where $2\delta_t$ is the 3dB beamwidth of the transmitter beam. Similarly

$$\beta_1 - \beta_m > \delta_r \quad . \tag{B.11}$$

We also need not consider angles where the contribution to the integral is less than ε, where ε is a program controllable accuracy parameter. Using the results of [Equation 8 in Parl, 1979] we get

$$(\alpha_1 + \beta_1)^{2-m} < \varepsilon_1(\alpha_m + \beta_m)^{2-m}$$

ϕ_t is calculated from $\phi_t = \phi - \phi_r$. The signs of ϕ_t and ϕ_r are checked. a_s is calculated from

$$(a_s - a_r) \cos \phi_r = 2a_r \sin^2(\phi_r/2) + X_2 \sin \Theta_{er} \quad .$$

The slant range d_0 between the terminals is given by

$$d_0^2 = a_t^2 + a_r^2 - 2a_t a_r \cos \phi$$

$$= (a_t - a_r)^2 + 4a_t a_r \sin^2(\phi/2) \quad .$$

The angles α_0 and β_0 are then given by

$$\sin \alpha_0 = \frac{X_2}{d_0} \sin \Theta_0$$

$$\sin \beta_0 = \frac{X_1}{d_0} \sin \Theta_0$$

$$\alpha_0 + \beta_0 = \Theta_0 \quad .$$

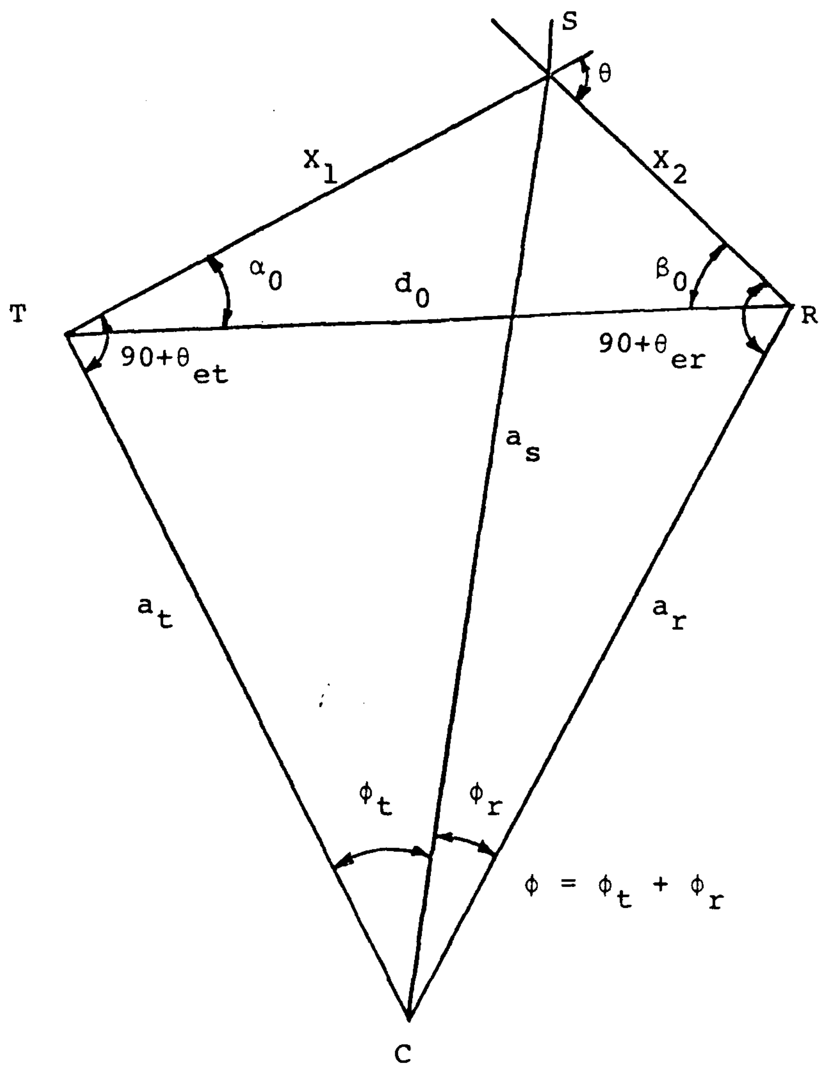


Figure B-2 Geometry for calculating the height and distance to a scattering point in the common volume.

where

$$\alpha_A = \alpha_0 + \psi_{te0} \quad .$$

The angle ν_t that the line to the scattering point makes with the antenna beam's boresight is then given by

$$\sin^2 \nu_T = 1 - \frac{|\underline{v}_{ts} \cdot \underline{v}_A|^2}{|\underline{v}_{ts}|^2}$$

$$= 1 - \frac{(R_{0T} \cos\psi_{ta0} \cos(\alpha - \alpha_A) + y \sin\psi_{ta0})^2}{R_{0T}{}^2 + y^2}$$

$$= [\sin^2\psi_{ta0} + \sin^2(\alpha - \alpha_A) \cos^2\psi_{ta0}$$

$$+ (y/R_{0T})^2 \cos^2\psi_{ta0}$$

$$- 2(y/R_{0T}) \cos(\alpha - \alpha_A) \cos\psi_{ta0} \sin\psi_{ta0}]$$

$$/[1 + (y/R_{0T})^2] \quad .$$

For the purpose of antenna gain calculation the following approximation is adequate:

$$\sin^2 \nu_T = [\sin^2(\alpha - \alpha_A) + (\sin \psi_{ta0} - y/R_{0T})^2]/(1 + (y/R_{OT})^2) \quad .$$

Similarly, for the receiver,

$$\sin^2 \nu_R = [\sin^2(\beta - \beta_A) + (\sin \psi_{ra0} - y/R_{0R})^2]/(1 + y/R_{0R})^2)$$

where

$$\beta_A = \beta_0 + \psi_{re0}$$

and

$$R_{0R} = \frac{d_0 \sin \alpha}{\sin(\alpha + \beta)} \quad .$$

B.8 CALCULATION OF RECEIVED POWER AND CORRELATIONS

The received power on a troposcatter link is

$$P_R = P_T G_T G_R C \iiint \frac{|g_T(\underline{r})|^2 \; |g_R(\underline{r})|^2}{R_R^2(\underline{r}) \; R_T^2(\underline{r})} \, \Theta(\underline{r})^{-m} \, d^3\underline{r} \qquad \text{(B.22)}$$

where

$G_T(G_R)$	=	the transmitter (receiver) gain.
P_T	=	transmitted power.
C	=	$\sigma_n^2 r_0^{\,3-m} \, k^{2-m} \, \Gamma(\frac{m}{2}) / [2\sqrt{\pi} \; \Gamma(\frac{m-3}{2})]$
$g_T(r) \;\; (g_R(r))$	=	voltage gain relative to boresight for transmitter (receiver).
$R_T(R_R)$	=	distance from scattering point to transmitter (receiver).
Θ	=	scattering angle.
m	=	spectrum slope of the refractive index.
σ_n^2	=	variance of the refractive index.
k	=	$2\pi/\lambda$ = wavenumber of the frequency of interest.

r_0 = correlation distance of the turbulent scatter.

For the Kolmogorov-Obukhov turbulence theory, the spectrum slope m is 11/3. In that case, it is customary to define the structure constant C_n^2 ,

$$C_n^2 = \sigma_n^2 r_0^{-2/3}\ 2^{1/3}\ \frac{\Gamma(2/3)}{\Gamma(4/3)} \ .$$

The constant C is then

$$C = C_n^2\ k^{-5/3}\ \Gamma(m-1)\ \sin\frac{\pi(m-3)}{2}\ /\ (8\pi)$$

$$= 0.0518\ k^{-5/3}\ C_n^2 \ . \qquad \text{(B.23)}$$

The constant C_n^2 is often measured as a function of height. For m = 11/3 the received power is

$$P_R = P_T G_T G_R\ 0.0518 k^{-5/3}\ C_n^2 \iiint \frac{|g_T|^2\ |g_R|^2}{R_R^2\ R_T^2}\ \theta^{-11/3} d^3\underline{r} \ . \qquad \text{(B.24)}$$

Observed values of m range from 2 to 5, but the mechanisms which causes values of m different from the 3.67 predicted by the turbulent scatter theory are not completely understood. It is generally assumed to be due to atmospheric layering and other nonhomogeneous or nonisotropic of effects. The NBS method uses m=5,

based on a large number of empirical results at lower frequencies. We wish to match the model to the NBS model for m=5, assuming nearly symmetrical paths. For $\Theta d < 10$ and for a surface refractivity $N_S \doteq 301$ the basic transmitter loss is

$$L_b = 135.8 + 30 \log \frac{f}{1\text{MHz}} + 30 \log \Theta + 10 \log \frac{d}{1\text{km}} + \frac{d\Theta}{1\text{km}} \quad (B.25)$$

$$= -74.2 + 30 \log f + 30 \log \Theta + 10 \log d + 0 + 0.332 \cdot 10^{-3} \Theta d.$$

The basic loss for m=5 is derived in Parl [1979],

$$L_p(m=5) = -10 \log(Cf^3) + 9.5 + 30 \log f + 30 \log \Theta + 10 \log d \quad (B.26)$$

The two expressions match when

$$-10 \log (Cf^3) = -83.7 + 0.332 \cdot 10^{-3} \Theta d \quad .$$

The Θd dependence can be attributed to the height dependence of the refractive index. For small take-off angles, we have

$$h \sim \frac{1}{8} d\Theta \quad .$$

Define

$$C_5 = k^3\, C(m{=}5) \quad .$$

We then get

$$C_5 = \left(\frac{2\pi}{c}\right)^3 f^3 C = 2.15 \cdot 10^{-3}\, e^{-h/1635} \tag{B.27}$$

For the turbulent scatter model (m=11/3) we use the Fried model for the height dependence of C_n^2 or equivalently σ_n^2 , but point out that there is a considerable variance in the observed profiles. For the Fried model we have

$$\sigma_n^2 = 6.7 \cdot 10^{-14} \exp(-h/3200)$$

and

$$r_0 = 2\sqrt{h} \quad .$$

Define now $C_{11/3}$ in the same way as above

$$C_{11/3} = k^{5/3}\, C(m = 11/3)$$

$$= 0.0518 C_n^2$$

$$= 0.0990\ \sigma_n^2\ r_0^{-2/3}$$

$$= 4.18 \cdot 10^{-15}\ h^{-1/3}\ \exp(-h/3200). \qquad (B.28)$$

The constant C can then be determined from (B.28) for $C_{11/3}$, and for m=5 it deviates by less than 1dB from the NBS model, i.e., (B.27); for 500m < h < 300 m. The correlation between two receiving beams is

$$P_{12} = P_T G_T G_R C \iiint \frac{|g_T|^2\ g_{R1} g_{R2}^{'}}{R_R^2\ R_T^2}\ \sigma^{-m} d^3\underline{r}$$

where g_{R1} and g_{R2} are the two beam patterns. For space or polarization diversity paths, it is necessary to include in the integral the phase difference from a scatterer to different terminals. When the profile C_n^2 is given (m=11/3 or m=5) then (B.23) must be used while keeping C_n^2 inside the integral. The computer program is designed to take this into account when indicated by the input data.

END

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